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A Computer Program for the Specification of Axial Compressor Airfoils

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A COMPUTER PROGRAM FOR THE SPECIFICATION OF AXIAL COMPRESSOR AIRFOILS

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FLUID DYNAMICS FACILITIES RESEARCH LABORATORY

PROJECT 7065

AIR FORCE SYSTEMS COMMAND

United States Air Force

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13. ABSTRACT

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DECEMBER 1972

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AEROSPACE RESEARCH LABORATORIES
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

1C

FOREWORD

This report was prepared by 1st Lt. George R. Frost and Dr. Arthur J. Wennerstrom of the Fluid Dynamics Facilities Research Laboratory, Aerospace Research Laboratories, Wright-Patterson Air Force Base, Ohio, and by Mr. Richard M. Hearsey of the University of Dayton Research Institute.

The report presents results from a portion of the effort of the Fluid Machinery Research Group, supervised by Dr. Arthur J. Wennerstrom and was conducted under Work Unit 09 of Project 7065, "Aerospace Simulation Techniques Research" under the overall direction of Mr. Elmer G. Johnson.

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This report is a revision and extension of ARL 70-0046. It describes the analysis in, and the use of, a computer program which has been developed for use in the design of axial compressor airfoils suitable for operation at high subsonic and supersonic Mach numbers. Four rather versatile camber line shapes and two thickness distributions are mathematically derived. These camber lines provide the capability of defining a wide variety of blades, from those of continuously positive camber to the so-called "S-blades", including many of the intermediate possibilities. A method is presented whereby the airfoils are specified on arbitrary axisymmetric streamsurfaces and then accurately redetermined in Cartesian coordinates on planes normal to the stacking axis. The program determines the coordinates, calculates section properties, and provides precision plots of the specified blade sections and the resulting blade projections on the above-mentioned planes.

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INTRODUCTION

The Fluid Dynamics Facilities Research Laboratory of the Aerospace Research Laboratories (ARL) is engaged in a program to find means of designing axial compressors capable of efficient performance at Mach numbers and pressure ratios beyond the current state-of-the-art. In conjunction with this effort, it was determined that general improvements could be made over some of the blade-design techniques now in popular use for high relative Mach numbers.

It is desirable when designing a compressor blade to create blade sections upon arbitrary surfaces of revolution that correspond to streamsurfaces indicated by the compressor design calculations. However, for manufacturing purposes, it is desirable to have blade surface coordinates for sections through the blade that are plane and perpendicular to the stacking axis. A method is presented whereby the blade is designed by creating sections on the streamsurfaces, and then determining coordinates for plane sections through the resultant blade.

Several objectives guide the aerodynamic design of any airfoil, whether for a compressor or any other purpose. First, and usually foremost, is the desire to keep the rate of diffusion as low as possible on the airfoil surfaces. While this objective does not change with Mach number, the shape of airfoil required to accomplish this can change significantly with Mach number. At supersonic Mach numbers there is generally little camber, and sometimes negative camber, in the leading edge region of a compressor blade. At these Mach numbers, minimizing diffusion rates means minimizing the suction surface supersonic expansion upstream of the inevitable passage shock or even producing a limited amount of supersonic diffusion upstream of the shock location. There are two principal methods of obtaining supersonic diffusion. When using blades having zero or positive camber near the leading edge, the diffusion may be obtained by a convergence of the annulus walls. If this is impractical, for example, in a high-aspect-ratio supersonic fan rotor, the same result can be accomplished by negative camber in the leading edge region of the airfoil. Blades which have negative camber followed by a region of positive camber have been called "S-blades".

A second objective is to define the airfoil in such a manner that its shape can be continuously varied to accommodate varying conditions along the blade span, thus maintaining resonable diffusion rates along each blade element. For example, it would be possible to define a type of profile

having a very attractive diffusion distribution for a hub section, but which could not be adapted to tip conditions, or vice versa. This would obviously be undesirable. It would generally be impractical to attempt to blend airfoil sections of more than one type along the span of a blade. A third objective for a desirable compressor blade is that the parameters determining its aerodynamic characteristics should be variable over a wide range within which there is little danger of producing shapes that are mechanically undesirable.

This report is a revision and extension of an earlier report (Reference 1) which presented two blade profiles which satisfy all the above requirements. They are composed of a common thickness distribution applied to two different camber lines: one a fourth-order polynomial, the other defined by two exponential functions. The thickness distribution consists of two third-order polynomials: one between the leading edge and the point of maximum thickness, and one from there to the trailing edge.

In addition to these camber lines, two other camber lines have been incorporated into the associated computer program. One of these is the familiar circular-arc camber line, upon which is placed the double-circular-arc thickness distribution. The second camber line may be composed of any pair of circular arcs, either of which may degenerate to a straight line, allowing for a wide range of design flexibility. This latter camber line, referred to as the multiple-circular-arc camber line in this report, uses the common thickness distribution of the original blade profiles and, as a special case, allows this thickness distribution to be applied to a simple circular-arc camber line.

The various camber lines and thickness distributions are described in Sections II and III.

In order to specify a blade for manufacture it is desirable to have coordinates for plane sections through the blade. For maximum accuracy, blade profiles should be designed on the arbitrary surfaces of revolution that typical current design procedures indicate. The method of satisfying these two requirements consists first of designing blade profiles on surfaces of revolution. Then a thin, uniformly-flexible beam is passed (mathematically) through like points on each profile and the intersection of the beam with the "manufacturing planes" yields the coordinates of the "manufacturing sections." The original report and computer program presented Equation (42) Reference 1, incorrectly which resulted in an improper determination of the Cartesian coordinates of the specified streamsurface blade sections for any non-cylindrical stream-surface. This led to associated errors in the determination of the manufacturing sections. (The magnitude of this error

increases with streamsurface slope angle and generally would not result in a blade leading or trailing edge angle error of more than about one degree.) The version of the program presented in this report incorporates the correct analysis as described in Section IV.

The fifth section of this report describes calculations to determine various properties of both the streamsurface blade profiles and the manufacturing sections. Several blade characteristics required for aerodynamic analysis of a resulting blade row are presented in Section VI.

In addition to the new features and the analysis correction already mentioned, the computer program (presented in Sections VII through IX) has been modified in several other respects since the original report was prepared. The program now accommodates curvilinear computing stations, as compared to the strictly linear stations previously required. An additional section property, the torsional constant, is calculated for the manufacturing sections to facilitate structural analysis of the blade. Finally, a blade may now be stacked also at either the leading or trailing edge, in addition to the previous capability of stacking at, or offset from, the section centroid.

The seventh section of this report presents a general user's guide for the computer program, and Section VIII presents several examples for the use of the program. The actual coding and a synopsis of the essential steps in the program logic, as well as information which may facilitate its implementation on a computing system, are presented in Section IX.

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SECTION II

THE SECTION CAMBER LINE

To obtain a camber line varying smoothly in curvature and satisfying the requirements of a compressor blade, it would be convenient to describe it mathematically in equation form. The type and order of such an equation will in turn be influenced by the boundary conditions which are imposed. The equation must be of high enough order to accommodate all of the necessary boundary conditions. Its order should be no higher than absolutely necessary, however, to minimize the number of singularities which can occur within its useful working range. In the following discussion, we shall consider an equation of the form $y = f(x)$ where the variable x is nondimensional and varies from 0 at the blade leading edge to 1.0 at the blade trailing edge. Furthermore, instead of defining the x-axis as the chord line, which is usual, x has been defined as the axial direction in the blade-element plane. This definition of the x-axis was chosen because it was found to lead to the simplest treatment of boundary conditions.

Three boundary conditions, or their equivalent, are absolutely necessary. One condition fixes a point on the line with respect to the coordinate system, another defines the slope at the leading edge, and the third defines the slope at the trailing edge. These three alone are sufficient to define a unique circular-arc camber line between the edge points. However, these boundary conditions are insufficient to define a camber line for a blade which will meet the special requirements of efficient operation at relatively high Mach numbers.

A characteristic usually desired for supersonic compressor blades is very little camber in the leading portion of the blade. Depending upon the overall aerodynamic design, the desired leading-edge camber may be negative, zero, or slightly positive. A convenient way of controlling this is to impose a boundary condition on the second derivative of the camber line at the leading edge. To put it in dimensionless form, we specify the ratio between second derivatives at the leading edge and the point where the absolute value of the second derivative is a maximum. A fifth condition was felt advisable for an efficient compressor blade. Namely, the first four conditions used alone tend to produce a blade whose curvature is highest at the trailing edge. This could result in large deviation angles and correspondingly high losses. Therefore, a condition was imposed on the second derivative at the trailing edge whereby its value could be specified as something less than the maximum. This boundary condition was phrased in exactly the same manner as at the leading edge. The resulting five conditions may be written

$$\text{At } x = 0: \quad y = 0 \tag{1}$$

$$y' = \tan \alpha_1$$

$$y'' = P\,(y'')_{max}$$

$$\text{At } x = 1: \quad y' = \tan \alpha_2 \tag{2}$$

$$y'' = Q\,(y'')_{max}$$

where prime (') and double prime (") refer to first and second derivatives respectively.

1. POLYNOMIAL CAMBER LINE

The five stated boundary conditions could be applied to a great number of equations to produce a camber line. A simple fourth order polynomial was chosen for the blade having primarily positive camber because it was convenient, and proved quite satisfactory. Since the second derivative of a fourth order polynomial is obviously second order and two of the boundary conditions apply to the second derivative, it was convenient to start by phrasing this in the form of a parabola. In standard form this can be written

$$(x - h)^2 = 4a\,(y'' - k) \tag{3}$$

or

$$y'' = \frac{1}{4a}(x - h)^2 + k$$

where h is the position on the x-axis where the second derivative is a maximum (or minimum) and k is the value which the second derivative has at this point. Integrating twice, one obtains

$$y' = \frac{1}{12}(x - h)^3 + kx + b \tag{4}$$

$$y = \frac{1}{48a}(x - h)^4 + \frac{k}{2}x^2 + bx + c \tag{5}$$

Application of the five boundary conditions to these equations produces the following result

$$\text{At } x = 0, \quad y = 0 \tag{6}$$

$$c = -\frac{h^4}{48a}$$

$$\text{At} \quad x = 0, \quad y' = \tan \alpha_1 \tag{7}$$

$$b = \frac{h^3}{12a} + \tan \alpha_1$$

$$\text{At} \quad x = 0, \quad y'' = P\,(y'')_{max}$$

$$k = -\frac{h^2}{4a\,(1-P)} \tag{8}$$

$$\text{At} \quad x = 1, \quad y' = \tan \alpha_2 \tag{9}$$

$$a = \frac{1}{4\,(\tan \alpha_1 - \tan \alpha_2)} \left[\frac{P}{1-P} h^2 + h - \frac{1}{3}\right]$$

$$\text{At} \quad x = 1, \quad y'' = Q\,(y'')_{max} \tag{10}$$

$$h = \frac{1}{1 + \sqrt{\frac{1-Q}{1-P}}}$$

The values of the input parameters at which the equations degenerate are easily ascertained by examining the derived constants. The values of the two blade angles may be anything between, and less than, ±90 degrees, measured from the axial direction. Note that when the two blade angles are the same, this fourth-order camber line becomes a straight line, regardless of what values P and Q may have. The parameter Q may be given any value between zero and 1.0. In practice, a value of 0.5 has proven very satisfactory for most applications. Singularities associated with the parameter P are partially dependent upon Q. At P = 1.0, a singularity exists independently of Q. However, if Q = 1.0, the equations also degenerate at P = -2.0 and if Q = 0, the equations degenerate at P = -3.0. In general, P should be greater than -2.0 and less than 1.0. For most applications, a value of P = 0 is quite satisfactory. Toward the hub of a compressor, it may be desirable to give P small positive values. Toward the tip, one might wish to use slightly negative values of P. However, this particular camber line does not produce an attractive "S-blade," especially

if the overall section camber is nearly zero. Negative values of P are only useful for delaying the onset of positive curvature by producing very slight negative cambers at the leading edge.

Figures 1 through 5 illustrate the general characteristics of this camber line. In Figure 1, the distribution of the second derivative of the camber line is shown for various values of P and blade angles characteristic of mid span. Figure 2 shows the actual camber lines which correspond to the curves shown in Figure 1. Figure 3 is similar to Figure 2 but shows the influence of P on a camber line more typical of a compressor hub section. Figure 4 illustrates the influence of Q for a camber line typical of mid span with P = zero. Finally, Figure 5 shows the different camber lines which result from varying the blade outlet angle with all other parameters fixed at typical values.

2. EXPONENTIAL CAMBER LINE

The exponential camber line is the result of efforts to find a mathematical expression capable of defining a satisfactory "S-blade." An "S-blade" should satisfy all of the basic criteria which led to the preceding polynomial camber line and, in addition, several conditions unique to the "S" configuration. Namely, it should be possible to locate the inflection point anywhere on the camber line, the blade angle at that point should be independently specifiable, and the method must work for overall blade cambers which are positive, zero, or negative. Furthermore, the transition across the inflection point should occur smoothly but rapidly so that a long straight region is avoided in the middle of the blade. It is also highly desirable that the equations allow a smooth transition from the "S" configuration to a more conventional one such as characterized by the polynomial camber line. To the list of five boundary conditions presented earlier, one is added:

$$\text{At} \quad x = s, \quad y' = \tan \alpha_s \tag{11}$$

Numerous equations, including polynomials, were examined with respect to the six boundary conditions. It soon became evident that more satisfactory results could be obtained by defining the camber line with two equations, one either side of the inflection point. As with the previous blade, it was easiest to choose an equation by examining equations for the second derivative of the camber line and then integrating twice to obtain the coordinate equation. The equation selected for both portions of the camber line is

$$y'' = b\,(x - s)\, e^{a(x-s)} \tag{12}$$

One set of constants applies from 0 to s and another set applies from s to 1.0. The maximum value of y" occurs where y''' = 0, which is at

$$x = s - \frac{1}{a} \tag{13}$$

Note that the constant a is positive ahead of the inflection point s, and is negative after it. The maximum (or minimum) value of the camber line second derivative for each camber line segment is

$$y''_{max} = -\frac{b}{ae} \tag{14}$$

Integrating the second-derivative equation twice, one obtains

$$y' = \frac{b}{a^2} e^{a(x-s)} [a(x-s) - 1] + c \tag{15}$$

$$y = \frac{b}{a^3} e^{a(x-s)} [a(x-s) - 2] + c\,(x-s) + d \tag{16}$$

This equation contains four arbitrary constants, and there are two sets to be determined as described above. Because there are different equations describing the two portions of the camber line, a seventh condition is added to the six already stated. At the inflection point, the coordinates of the camber line are the same on both lines.

Applying the four conditions appropriate for the leading portion of the camber line produces the following result:

At $x = 0, \quad y = 0$

$$d_1 = (a_1 s + 2) \frac{b_1}{a_1^{\,3}} e^{-a_1 s} \tag{17}$$

At $x = 0$, $y' = \tan \alpha_1$

$$c_1 = \tan \alpha_1 + (a_1 s + 1) \frac{b_1}{a_1{}^2} e^{-a_1 s}$$

At $x = 0$, $y'' = P\,(y''_{max})$

$$P = a_1 s e^{(1-a_1 s)} \tag{18}$$

At $x = s$, $y' = \tan \alpha_s$ (19)

$$c_1 = \tan \alpha_s + \frac{b_1}{a_1{}^2}$$

Equating the two expressions for c_1 yields

$$b_1 = \frac{a_1{}^2(\tan \alpha_1 - \tan \alpha_s)}{1 - (a_1 s + 1)e^{-a_1 s}} \tag{20}$$

Applying the four conditions appropriate for the rearward portion of the camber line produces the following result:

At $x = s$, $y' = \tan \alpha_s$

$$c_2 = \tan \alpha_s + \frac{b_2}{a_2{}^2} \tag{21}$$

At $x = s$, $y = y$ obtained from Equation (16) for the leading portion of the camber line.

$$d_2 = 2\left(\frac{b_2}{a_2{}^3} - \frac{b_1}{a_1{}^3}\right) + s\,(c_1 - c_2) + d_1$$

At $x = 1$, $y' = \tan \alpha_2$

$$c_2 = \tan \alpha_2 - \frac{b_2}{a_2{}^2} e^{a_2(1-s)} \, [a_2(1-s) - 1] \tag{22}$$

Equating the two expressions for c_2 yields

$$b_2 = \frac{a_2{}^2(\tan\alpha_2 - \tan\alpha_s)}{1 + [a_2(1-s) - 1]\, e^{a_2(1-s)}} \quad (23)$$

$$\text{At } x = 1, \quad y'' = Q\,(y''_{max})$$

$$Q = (s-1)a_2 e^{1+a_2(1-s)} \quad (24)$$

The equations obtained to determine a_1 and a_2 (Equations (18) and (24))are implicit, and require iterative solution. In each case, there are two solutions for the constant (assuming P and Q to be less than unity). Because it is desired that the magnitude of the second derivative reach its maximum value between the inflection point and leading or trailing edge, as appropriate, it follows that

$$a_1 > \frac{1}{s} \quad (25)$$

and

$$a_2 < \frac{1}{s-1}$$

Figures 6 through 10 illustrate the general characteristic of this camber line. Figure 6 shows the distribution of the second derivative of the camber line for various values of P and Q. The other parameters that are held constant describe a blade perhaps typical of mid-span conditions for a high-speed machine. Figure 7 shows the corresponding camber line. Figure 8 shows camber lines for a section having zero overall camber and hence equal negative and positive cambers. The effect of varying the parameters P and Q is shown. Figure 9 shows camber lines for a similar section, except that the effect of varying the location of the inflection point S is illustrated. Camber lines for three sections having no negative camber are shown in Figure 10. As the "inflection point" is shifted rearwards from the leading edge, the camber line changes from one of continuous positive camber to that of a "J-blade."

3. CIRCULAR-ARC CAMBER LINE

The circular-arc camber line has been considered because of the wide application of the double-circular-arc airfoil in turbo-machinery of the more conventional variety and because of its potential use, particularly with respect to stators, in

high performance compressor stages. Of the original five boundary conditions of Equations (1) and (2), those involving y" are superfluous to the definition of a unique circular-arc camber line.

The equation of this camber line is of the form

$$(x - x_0)^2 + (y - y_0)^2 = R^2 \tag{26}$$

where (x_0, y_0) is the center of, and R the radius of, the circle of which the desired arc is a portion.

From the boundary condition at x = 1 and the knowledge that the slope of a radial line at any point must equal the negative reciprocal of the slope of the tangent to the arc at that point, one obtains

$$\tan \alpha_2 = - \frac{(1 - x_0)}{y_2 - y_0} \tag{27}$$

where y_2 is the y coordinate of the arc at x = 1. Solving for x_0,

$$x_0 = (y_2 - y_0) \tan \alpha_2 + 1 \tag{28}$$

At the point $(1, y_2)$, Equation (26) may be arranged to yield

$$(y_2 - y_0)^2 = R^2 - x_0{}^2 + 2x_0 - 1 \tag{29}$$

From the boundary condition which fixes the leading edge of the arc at the origin of the coordinate system, and Equation (26), one obtains

$$y_0{}^2 = R^2 - x_0{}^2 \tag{30}$$

Substituting Equations (28) and (30) into Equation (29),

$$(y_2 - y_0)^2 = y_0{}^2 + 2 (y_2 - y_0) \tan \alpha_2 + 1 \tag{31}$$

Expanding the left hand side of Equation (31) and solving for y_0,

$$y_0 = \frac{y_2{}^2 - 2y_2 \tan \alpha_2 - 1}{2(y_2 - \tan \alpha_2)} \tag{32}$$

Using this expression for y_0 in Equation (28),

$$x_0 = \frac{(y_2{}^2 - 1) \tan \alpha_2 + 2y_2}{2(y_2 - \tan \alpha_2)} \tag{33}$$

and substituting Equations (32) and (33) into (30) and solving for R^2,

$$R^2 = \frac{(y_2{}^2 + 1)^2 \sec^2 \alpha_2}{4(y_2 - \tan \alpha_2)^2} \tag{34}$$

The above equations (Equations (32), (33) and (34)) give the necessary camber line constants in terms of the as yet undetermined y_2. The third boundary condition, fixing the slope at the origin, is employed to express y_2 in terms of known quantities. From this boundary condition,

$$x_0 = -y_0 \tan \alpha_1 \tag{35}$$

Combining Equations (28) and (33) and solving for y_2,

$$y_2 = \frac{y_0 (\tan \alpha_2 - \tan \alpha_1) - 1}{\tan \alpha_2} \tag{36}$$

Substituting this expression for y_2 into Equation (32) yields, after considerable simplification,

$$y_0 = \frac{- \tan \alpha_1 \sec^2 \alpha_2 \pm \tan \alpha_2 \sec \alpha_1 \sec \alpha_2}{\tan^2 \alpha_1 - \tan^2 \alpha_2} \tag{37}$$

The proper sign of the second term ($\mp$) of Equation (37) is determined by the realization that $|y_0|$ must approach infinity as α_2 approaches α_1. Therefore,

$$y_0 = \frac{-(\tan \alpha_1 \sec^2 \alpha_2 + \tan \alpha_1 \sec \alpha_1 \sec \alpha_2)}{\tan^2 \alpha_1 - \tan^2 \alpha_2} \tag{38}$$

Substitution of Equation (38) into Equation (35) determines x_0 in terms of known quantities. Substitution of Equation (38) into (36) determines y_2 in terms of the known quantities α_1 and α_2, which, when used in Equation (34), yields an expression for R^2 in terms of α_1 and α_2. This completes the determination of the three constants (x_0, y_0, and R^2) of the circular arc camber line.

4. MULTIPLE-CIRCULAR-ARC CAMBER LINE

The multiple-circular-arc camber line incorporates and extends the circular-arc definition scheme as previously described to include the potential for defining a camber line composed of two segments, either or both of which may be either circular arcs or straight lines, in principle. The most interesting applications of this capability probably involve the creation of "S-blades," composed of two circular arcs, and "J-blades" composed of a straight-line and circular-arc combination.

The specification of this two-segment camber line requires the boundary condition of Equation (11) as well as the three boundary conditions necessary for the circular-arc camber line. The circular-arc portions are computed in the manner of the subsection "Circular-Arc Camber Line" using the inflection angle and the inlet (or outlet) angle. Each segment is scaled, and positioned with respect to the origin (if necessary). A straight-line segment is created when the angle at the inflection point is identical to the inlet (or outlet) angle.

One other feature of the programming associated with the multiple-circular-arc camber line should be noted: an ordinary circular-arc camber line will be produced if the inflection point is specified at the blade leading edge. Since the standard thickness distribution (described in Section III) is applied to the multiple-circular-arc camber line, this feature enables the program user to define a blade using the circular-arc camber line and either the standard or double circular-arc thickness distribution.

Figure 11 shows various types of camber lines which may be specified using the multiple-circular-arc camber line option.

Figure 12 shows camber lines for similar "S-blade" sections, illustrating the effect of varying the location of the inflection point. Camber lines for three "J-blade" sections with different inflection locations are shown in Figure 13.

SECTION III

THE SECTION THICKNESS DISTRIBUTION

1. STANDARD THICKNESS DISTRIBUTION

For the same reasons that it was desirable to define the camber line in equation form, it is also practical to define the thickness distribution this way. Five features were particularly desired for a supersonic compressor airfoil. First, the maximum thickness should be arbitrary. Second, it should be possible to locate the maximum thickness at any point on the downstream half of the airfoil. Third, there should be no discontinuity in curvature, meaning that derivatives through the second should be continuous. Fourth, for mechanical reasons, the airfoil should have a thickness distribution which is continuously convex; i.e., the second derivative should not change sign. Fifth, the airfoil should have the slenderest leading edge that is compatible with the first four conditions.

Numerous equations were examined with these objectives in mind. However, no single equation was found which seemed to satisfy all of the foregoing requirements to a satisfactory extent. The method finally selected consisted of defining the thickness distribution with two equations: one from the leading edge to the point of maximum thickness and one from there to the trailing edge. At the point of juncture, the thickness and the first and second derivatives of thickness were equated. In order to prevent a reflex curvature from occurring in the thickness distribution near the leading edge, the second derivative of thickness was set equal to zero at the leading edge. Thickness was considered to be distributed normal to a camber line of unit length. Maximum thickness was located at a point Z on this axis which, it should be noted, is not the chord line. The thickness of the leading and trailing edges is independently specified so that it need not be the same at both edges. At the leading edge, the blade surface is completed with a circular arc. At the trailing edge, the blade was truncated by connecting the two end points with a straight line.

The boundary conditions chosen for the two segments of the thickness distribution may be summarized as follows.

For the Leading Portion:

$$\text{At} \quad x = 0, \; y = y_0 \qquad (39)$$
$$y'' = 0$$
$$\text{At} \quad x = Z, \; y = T/2$$
$$y' = 0$$

For the Trailing Portion:

$$\text{At} \quad x = Z, \quad y = T/2 \qquad (40)$$
$$y' = 0$$
$$y'' = y''_{(\text{leading portion})}$$
$$\text{At} \quad x = 1.0, \quad y = y_1$$

Note that y represents the half-thickness of the blade element and T is the total value of the maximum thickness. Both are scaled in proportion to a camber line length of unity. The parameter Z denotes the position where maximum thickness occurs on the camber line. For the leading section, a simple third-order polynomial was used in the form

$$y = ax^3 + bx^2 + cx + d \qquad (41)$$
$$y' = 3ax^2 + 2bx + c$$
$$y'' = 6ax + 2b$$

Applying the boundary conditions for this portion produces the following result valid from 0 to Z:

$$a = -\frac{T/2 - y_0}{2Z^3} \qquad (42)$$
$$b = 0$$
$$c = \frac{3(T/2 - y_0)}{2Z} \qquad (43)$$
$$d = y_1 \qquad (44)$$

Also, at $x = Z$ (45)

$$y'' = -\frac{3(T/2 - y_0)}{Z^2}$$

which is used as a boundary condition for the trailing portion of the blade. A similar third-order equation was used to define the trailing portion of the thickness distribution. This was arranged

$$y = e(x-Z)^3 + f(x-Z)^2 + g(x-Z) + h \qquad (46)$$

$$y' = 3e(x-Z)^2 + 2f(x-Z) + g$$

$$y'' = 6e(x-Z) + 2f$$

Applying the boundary conditions relating to the trailing portion leads to the following result valid from $x = z$ to 1.0.

$$e = \frac{3(T/2-y_0)}{2Z^2(1-Z)} - \frac{(T/2-y_1)}{(1-Z)^3} \qquad (47)$$

$$f = -\frac{3(T/2-y_0)}{2Z^2} \qquad (48)$$

$$g = 0 \qquad (49)$$

$$h = T/2$$

As the equations for the two portions of the thickness distribution are cubics, potentially there is the possibility of introducing inflection points into the thickness distribution. One boundary condition applied to the equation describing the forward portion of the thickness was that the second derivative be zero at the leading edge. Hence, because a cubic has only one point of inflection, the thickness distribution forward of the point of maximum thickness cannot contain an inflection. Examination of the equation for the second portion of the thickness distribution yields the result that there is a minimum value of Z (the point of maximum thickness) such that the inflection point of this equation is not on the blade surface. This is given by

$$Z_{min} = \frac{1}{1 + \sqrt{\frac{1-2y_1/T}{1-2y_0/T}}} \tag{50}$$

Thus if the leading and trailing edge thicknesses are equal, Z_{min} is 0.5, and will increase as the ratio of the trailing edge to leading edge thicknesses increases.

Figure 14 shows thickness distributions for three values of Z, with the leading and trailing edge thicknesses equal in each case.

2. DOUBLE-CIRCULAR-ARC THICKNESS DISTRIBUTION

The determination of the double-circular-arc thickness distribution is essentially a geometrical exercise involving the translation and rotation of coordinate systems and the use of polar coordinates for the sake of simplicity and convenience.

The most desirable coordinate system would define the circular arc camber line as part of a circle centered at the origin, such that the camber line represents the portion of the circle in the range

$$\frac{\pi}{2} - \frac{\phi}{2} \le \psi \le \frac{\pi}{2} + \frac{\phi}{2} \tag{51}$$

when ψ is measured counterclockwise from the positive x axis and, from geometry,

$$\phi = \alpha_1 - \alpha_2 \tag{52}$$

This combined translation-rotation is accomplished by the coordinate change

$$x' = (x-x_1)\cos\rho + (y-y_1)\sin\rho \tag{53}$$

$$y' = -(x-x_1)\sin\rho + (y-y_1)\cos\rho$$

where

$$\rho = N + \frac{\phi}{2} \tag{54}$$

From the geometry of the camber line,

$$N = \sin^{-1}\left[\frac{(x_0 - 1)}{R}\right] \tag{55}$$

In the new coordinate system, then,

$$x'^2 + y'^2 = R^2 \tag{56}$$

In this system, either surface of the airfoil may be expressed as a portion of a circle centered on the y' axis. That is,

$$x'^2 + (y' - y_s)^2 = R_s^{\,2} \tag{57}$$

or, expanding,

$$x'^2 + y'^2 - 2y'\,y_s + y_s^{\,2} = R_s^{\,2} \tag{58}$$

In cylindrical polar coordinates, Equations (56) and (58) may be expressed as follows

$$r_1 = R \tag{59}$$

$$r_2^{\,2} + y_s^{\,2} - 2\,r_2\,y_s \sin\psi = R_s^{\,2} \tag{60}$$

where the relevant range of ψ is as given in Equation (51).

The desired thickness is the difference (Δr) between the expressions for the two arcs. First, however, Equation (60) must be solved for r_2 rather than $r_2^{\,2}$. Using the binomial theorem,

$$r_2 = y_s \sin\psi \pm \sqrt{R_s^{\,2} - y_s^{\,2}\cos^2\psi} \tag{61}$$

If it is stipulated that Equation (61) represents the surface of the blade which lies further from the origin than does the camber line, then the thickness t in a positive sense is given by the expression $r_2 - r_1$.

$$t = y_s \sin\psi \pm \sqrt{R_s^2 - y_s^2 \cos^2\psi} - R \tag{62}$$

The proper sign of the second term (+) is chosen by requiring that at $\psi = \pi/2$,

$$t = y_s + R_s - R \tag{63}$$

Therefore, Equation (62) becomes

$$t = y_s \sin\psi + \sqrt{R_s^2 - y_s^2 \cos^2\psi} - R \tag{64}$$

A further rotation of the coordinate system such that

$$\mu = \psi - \left(\frac{\pi}{2} - \frac{\phi}{2}\right) \tag{65}$$

yields

$$t = y_s \cos\left[\frac{\phi}{2} - \mu\right] + \sqrt{R_s^2 - y_s^2 \sin^2\left[\frac{\phi}{2} - \mu\right]} - R \tag{66}$$

in the range $0 \leq \mu \leq \phi$.

Expressing Equation (66) in terms of the normalized arc length, s,

$$t = y_s \cos\left[\left(\frac{1}{2} - s\right)\phi\right] + \sqrt{R_s^2 - y_s^2 \sin^2\left[\left(\frac{1}{2} - s\right)\phi\right]} - R \tag{67}$$

in the range $0 \leq s \leq 1$.

The expressions for y_S and R_S in Equation (67) can be determined geometrically in terms of T/2 and r_0, the edge radius.

$$R_s = r_0 + \frac{R \sin\phi}{\sin\left[\operatorname{Arccos}\left(\frac{1-A^2}{1+A^2}\right)\right]} \tag{68}$$

$$y_s = R - R_s + \frac{T}{2} \tag{69}$$

where

$$A = \frac{(T/2 - r_0) + R\,(1 - \cos\phi/2)}{R \sin\phi/2} \tag{70}$$

Equations (68), (69) and (70) yield all the unknown constants of the thickness distribution in terms of known quantities.

SECTION IV

CARTESIAN COORDINATES FOR THE BLADE

The two previous sections have described the methods derived to specify individual blade sections. When located as desired relative to the blade stacking axis, the section coordinates are the coordinates of the streamsurface blade section. A series of such sections on all given stream surfaces specifies the envelope of the blade, but the surface coordinates are not in a convenient form for manufacturing purposes. A method of determining the coordinates of plane sections through the blade at a series of locations along the stacking axis is now described.

The method relies upon the use of the "spline-curve" for interpolation (or extrapolation) of the coordinates of the blade surfaces and therefore the theory of the curve is given. The same interpolation scheme is also used elsewhere in the computer program.

Given the Cartesian coordinates x and y for a series of points, the problem is to find a curve y = f(x) that passes through each given point. A series of algebraic cubics is used, one equation applying between each adjacent pair of points. The four coefficients for each cubic permit the matching of the first and second derivatives of the two equations applying at each point (except the first and last), in addition to passing the curves through the specified points. Two additional conditions are required to establish the coefficients. Those chosen here are that the second derivatives of the equations at the first and last points are zero. Other conditions are possible, but less appropriate for the current purpose. A curve of the form described is that theoretically assumed by a thin, uniformly-flexible beam pinned at each specified point, hence the name "spline-curve."

By applying the conditions described above, the following system of equations may be produced. In the interval between any two adjacent points, such that $x_{n-1} \le x \le x_n$, the equation of the spline-curve is

$$y = \frac{M_{n-1}}{6} \frac{(x_n - x)^3}{(x_n - x_{n-1})} + \frac{M_n}{6} \frac{(x - x_{n-1})^3}{(x_n - x_{n-1})} + (x_n - x)\left[\frac{y_{n-1}}{x_n - x_{n-1}} - \frac{M_{n-1}}{6}(x_n - x_{n-1})\right] +$$

$$(x - x_{n-1})\left[\frac{y_n}{x_n - x_{n-1}} - \frac{M_n}{6}(x_n - x_{n-1})\right] \tag{71}$$

and the slope of the spline-curve is

$$\frac{dy}{dx} = -\frac{M_{n-1}}{2}\frac{(x_n-x)^2}{(x_n-x_{n-1})} + \frac{M_n}{2}\frac{(x-x_{n-1})^2}{(x_n-x_{n-1})} + \left(\frac{y_n-y_{n-1}}{x_n-x_{n-1}}\right) - \left(\frac{M_n-M_{n-1}}{6}\right)(x_n-x_{n-1}) \tag{72}$$

The coefficients M are given by $M_1 = M_N = 0.0$ where N is the total number of specified points, and

$$M_n = \frac{D_n - B_n M_{n+1}}{A_n} \tag{73}$$

$$A_1 = 1.0$$

$$B_1 = 0.0$$

$$D_1 = 0.0$$

$$A_n = \frac{(x_{n+1}-x_{n-1})}{3} - \frac{(x_n-x_{n-1})}{6}\frac{B_{n-1}}{A_{n-1}}$$

$$B_n = \frac{x_{n+1}-x_n}{6}$$

$$D_n = \frac{y_{n+1}-y_n}{x_{n+1}-x_n} - \frac{y_n-y_{n-1}}{x_n-x_{n-1}} - \frac{(x_n-x_{n-1})}{6}\frac{D_{n-1}}{A_{n-1}}$$

Hence the coefficients M may be found by first computing the coefficients A, B and D.

In order to use the spline-curve for interpolation, it is convenient first to compute the M coefficients for all the specified points, and then to evaluate the value of the function y at the desired value (or values) of x, using the coefficients appropriate to the interval in which x lies. Should extrapolation outside the specified range of values of x be required, this is done assuming a straight line at the slope of the spline-curve at the appropriate end-point.

The determination of the Cartesian coordinates of the manufacturing sections involves two steps. First, Cartesian coordinates for the points defining the streamsurfaces are obtained. Second, coordinates for the manufacturing sections are interpolated (or extrapolated) at the desired plane sections through the blade.

Figure 15 illustrates the geometry involved in the determination of the Cartesian coordinates of the streamsurface sections. The radius of the streamsurface is defined at a number of axial locations. A spline-curve is passed through these points, and the slope of the streamsurface is calculated (as the slope of the spline-curve) at 100 points distributed uniformly on the x-axis between the first and last given points. Then an m-x table is constructed by numerically integrating for the streamsurface using

$$m_n = m_{n-1} + (x_n - x_{n-1}) \sqrt{1 + \left[\left(\frac{dr}{dx_n} + \frac{dr}{dx_{n-1}}\right)\Big/2\right]^2} \qquad (74)$$

The m coordinate of any point on the streamsurface blade section is the "axial" coordinate of the point derived from the camber line and thickness distribution. Thus linear interpolation of the m-x table yields the corresponding x coordinate. Use of a 100-point table assures that linear interpolation is adequate. The r-x table given enables the radius of the streamsurface at any value of x to be found. Spline-curve interpolation is used for this purpose.

The "y" coordinate of any point derived from the camber line and thickness distribution must now be related to the circumferential direction on a streamsurface. This can be accomplished by determining the angle ε (defined in Figure 15) in the following manner. First, the origin of the m-system is shifted so that the origin (m = 0) corresponds to the location of the centroid of the section in the cascade plane. The camber line slopes in the cascade plane must then be reproduced on a streamsurface. This requires that at each point

$$r \frac{d\varepsilon}{dm} = \frac{dy}{dx} = y' \qquad (75)$$

It is possible to determine the variation of ε with m by integrating Equation (75) with respect to m,

$$\varepsilon(m) - \varepsilon_o = \int_0^m \frac{y'}{r}\, dm \qquad (76)$$

where both the streamsurface radius and the camber line slope are known functions of x, hence m.

At $m = 0$,

$$\varepsilon_o = \frac{y_d}{r_d} \tag{77}$$

where y_d is the distance between the section centroid and the camber line measured in the y direction in the cascade plane, and r_d is the streamsurface radius.

Therefore, from Equations (76) and (77),

$$\varepsilon(m) = \int_0^m \frac{y'}{r}\, dm + \frac{y_d}{r_d} \tag{78}$$

For each point on the blade surface in the cascade plane, the appropriate ε is determined through a six step procedure:

(1) m is determined from the m-x table

(2) $\varepsilon_{camber\ line}$ is determined from Equation (78)

(3) Δy is determined from $y = y_{surface} - y_{camber\ line}$ in the cascade plane

(4) r is determined from the value of m in conjunction with the m-x and r-x tables

(5) $\Delta\varepsilon$ is determined from $\Delta\varepsilon = \Delta y/r$

(6) $\varepsilon_{surface} = \varepsilon_{camber\ line} + \Delta\varepsilon$

The two remaining Cartesian coordinates of the point then follow from

$$z = r \cos \varepsilon \quad \text{and} \quad y = r \sin \varepsilon \tag{79}$$

The interpolation of x and y coordinates for the manufacturing sections (on constant-z planes) is achieved by fitting the spline-curve through corresponding points on each streamsurface section. The same number of points is used to define each blade section. Hence, the spline-curve is used first to fit x as a function of z for the first point on the suction

surface of each section. The value of x is then interpolated at each desired value of z. Then this is repeated for the coordinate y, and then for all other corresponding points describing the streamsurface sections. Thus an equal number of similarly distributed points describing the manufacturing sections is obtained.

SECTION V

SECTION PROPERTIES

The stacking axis of the blade is passed through each streamsurface section either at its leading or trailing edge, or at a point specified relative to the centroid of the section. Because the streamsurface sections are in general not planar, the centroids of the manufacturing sections will not generally lie precisely on the stacking axis when the streamsurface sections are stacked about their centroids. By determining the locations of the centroids of the manufacturing sections so obtained, it is possible to estimate the offsets that must be applied when restacking the streamsurface sections in order that the centroids of the manufacturing sections will be located as desired relative to the stacking axis. Thus there is a requirement to determine the locations of the centroids of both the streamsurface and manufacturing sections if the blade is to be stacked on the centroids.

To further assist in any mechanical analysis of the blade, the areas, second moments of area, principal axes, and principal second moments of area for both the streamsurface and manufacturing sections are also determined. The methods used to determine these quantities are given below.

1. STREAMSURFACE SECTIONS

The location of the centroid of an area relative to an arbitrary origin is given by

$$\bar{x} = \frac{\int x\,dA}{\int dA} \quad \text{and} \quad \bar{y} = \frac{\int y\,dA}{\int dA} \tag{80}$$

In the computer program these integrals are performed numerically by considering the section to be composed of a semicircle formed by the leading edge and a series of quadrilaterals. The quadrilaterals are defined by the series of points defining the camber line and the values of the section thickness at these points, as shown in Figure 16. The origin for the calculation is the leading edge of the blade and each quadrilateral is assumed to be a rectangle. The length of one side is the camber line length enclosed by the quadrilateral, and the length of the other is the mean section thickness at the ends of the quadrilateral. Hence the above relationships are evaluated as

$$\int x\,dA = \frac{\pi y_0^2}{2}\left(y_0 - \frac{4}{3}\frac{\cos\alpha_1}{\pi}y_0\right) + \sum_{1,N-1}\left(\frac{xm_n+xm_{n+1}}{2}\;(s_{n+1}-s_n)\;\frac{(t_{n+1}-t_n)}{2}\right) \tag{81}$$

$$\int y\,dA = -\frac{\pi y_0^2}{2}\frac{4y_0}{3\pi}\sin\alpha_1 + \sum_{1,N-1}\left(\frac{ym_n+ym_{n+1}}{2}\;(s_{n+1}-s_n)\;\frac{(t_n+t_{n+1})}{2}\right) \tag{82}$$

$$\int dA = \frac{\pi y_0^2}{2} + \sum_{1,N-1}(s_{n+1}-s_n)\;\frac{(t_n+t_{n+1})}{2} \tag{83}$$

For the case of the double-circular-arc blade, a term representing the contribution of the trailing edge semicircle, similar to the term for the leading edge contribution, is added to each of Equations (81), (82) and (83).

The second moments of area I_x and I_y, and products of inertia, I_{xy}, are found by again considering the section to be composed of a series of rectangles, as shown in Figure 16. (The contribution of the edge(s) is neglected.) The principal second moments of one rectange about its centroid are

$$I_{x'} = (s_{n+1}-s_n)\left(\frac{t_{n+1}+t_n}{2}\right)^3 \Big/ 12 \tag{84}$$

$$I_{y'} = \left(\frac{t_{n+1}+t_n}{2}\right)(s_{n+1}-s_n)^3 / 12 \tag{85}$$

The mean camber line angle, C, at the two ends of the rectangle is used to determine the second moments of area of the rectangle about its centroid from

$$I_x = \frac{I_{x'}+I_{y'}}{2} + \frac{I_{x'}-I_{y'}}{2}\cos(2C) \tag{86}$$

$$I_y = \frac{I_{x'}+I_{y'}}{2} - \frac{I_{x'}-I_{y'}}{2}\cos(2C) \tag{87}$$

The product of inertia of the rectangle is also determined from

$$I_{xy} = \frac{(I_x - I_y)\cos(2C) - I_{x'} + I_{y'}}{2\sin(2C)} \tag{88}$$

The contributions of the rectangle to the second moments of area of the section about its centroid are given by

$$\Delta I_x \text{ (section centroid)} = I_x + A(y-\bar{y})^2 \tag{89}$$

$$\Delta I_y \text{ (section centroid)} = I_y + A(x-\bar{x})^2 \tag{90}$$

where A is the area of the rectangle, and $\bar{x}$ and $\bar{y}$ are the coordinates of the center (that is, centroid) of the rectangle. Also, the contribution of the rectangle to the product of inertia of the section about its centroid is given by

$$\Delta I_{xy}\text{(section centroid)} = I_{xy} + A(x-\bar{x})\ (y-\bar{y}) \tag{91}$$

The summation of all such contributions yields the second moments of area and product of inertia of the section about its centroid.

The inclination of the principal axes of the section, B, is given by

$$B = \frac{1}{2}\arctan\left(\frac{2I_{xy}}{I_y - I_x}\right) \tag{92}$$

The principal second moments of area of the section about its centroid are given by

$$I_{xp} = \frac{I_x + I_y}{2} + \frac{I_x - I_y}{2}\cos(2B) - I_{xy}\sin(2B) \tag{93}$$

$$I_{yp} = \frac{I_x + I_y}{2} - \frac{I_x - I_y}{2}\cos(2B) + I_{xy}\sin(2B) \tag{94}$$

The various calculations described above are made for a "normalized" streamsurface blade section (that is one having an axial chord of unity), and are subsequently scaled as appropriate, according to the specified chord length.

2. MANUFACTURING SECTIONS

The methods used to determine the properties of the manufacturing sections are essentially the same as those described above for the streamsurface sections. However, in this case the section geometry is described by the coordinates of a series of points on the two blade surfaces as shown in Figure 16.

The section is again considered to be composed of a semicircle at the leading edge and a number of rectangles. The radius of the leading edge, y_0, is calculated to be a half of the distance between the first points on the blade pressure and suction surfaces. The angle of the blade section at the leading edge is obtained from the first two points on each blade surface, thus

$$\alpha = \arctan\left(\frac{yp_2+ys_2-yp_1-ys_1}{xp_2+xs_2-xp_1-xs_1}\right) \tag{95}$$

The lengths of the sides of each assumed rectange are determined from the coordinates of the points at the four corners, thus

$$\ell_n = \frac{1}{2}\left\{\sqrt{[(xs_{n+1}-xp_{n+1})^2 + (ys_{n+1}-yp_{n+1})^2]} + \sqrt{[(xs_n-xp_n)^2 + (ys_n-yp_n)^2]}\right\} \tag{96}$$

$$m_n = \frac{1}{2}\left\{\sqrt{[(xs_{n+1}-xs_n)^2 + (ys_{n+1}-ys_n)^2]} + \sqrt{[(xp_{n+1}-xp_n)^2 + (yp_{n+1}-yp_n)^2]}\right\} \tag{97}$$

Hence, the section area and the location of the centroid are determined from

$$\int dA = \frac{\pi y_0{}^2}{2} + \sum_{1,N-1} (\ell_n m_n) \tag{98}$$

$$\int x\,dA = \frac{\pi y_0^{\,2}}{2}\left[(xp_1+xs_1)/2\cdot 0-\frac{4y_0}{3\pi}\cos\alpha\right] + \tag{99}$$

$$\sum_{1,N-1}\left[\ell_n m_n(xs_n+xp_n+xp_{n+1}+xs_{n+1})/4.0\right]$$

$$\int y\,dA = \frac{\pi y_0^{\,2}}{2}\left[(yp_1+ys_1)/2.0-\frac{4y_0}{3\pi}\sin\alpha\right] + \tag{100}$$

$$\sum_{1,N-1}\left[\ell_n m_n(ys_n+ys_{n+1}+yp_n+yp_{n+1})/4.0\right]$$

As for the streamsurface sections, an additional term is inserted in each of Equations (98), (99) and (100) for the double-circular-arc blade, to account for the contribution of the trailing edge semi-circle.

The second moments of area and product of inertia of the section are again found by first determining the principal second moments of each rectangle about its centroid, and then determining the contribution of each rectangle to the second moments and product of inertia of the section. Referring again to Figure 16, we have for one rectangle

$$I_{x'} = m\ell^3/12 \tag{101}$$

$$I_{y'} = \ell m^3/12 \tag{102}$$

In order to determine the second moments of area of the rectangle about is centroid in directions parallel to the axis of the section coordinates, the angle of inclination of the rectangle is found from

$$A = \arctan\left(\frac{yp_{n+1}+ys_{n+1}-yp_n-ys_n}{xp_{n+1}+xs_{n+1}-xp_n-xs_n}\right) \tag{103}$$

Then the second moments of area and product of inertia for the rectangle are found using Equations (86), (87) and (88) again, and the contributions of the rectangle to the properties

of the sections are given by Equations (89), (90) and (91). Equations (92), (93) and (94) are applied to give the inclination of the principal axes, and the principal second moments of the section about its centroid.

An additional section property, the torsional constant, is computed for the manufacturing sections. Following Reference 2, the constant K is determined from

$$K = \frac{\frac{1}{3}F}{\left(1+\frac{4}{3}\,\frac{F}{Su^2}\right)} \tag{104}$$

where

$$F = \int_0^u t^3 \; du \tag{105}$$

and du, t, and S are the elemental length along the section median line, the thickness normal to the median line, and the section area, respectively.

SECTION VI

BLADE CHARACTERISTICS

1. BLADE VOLUME CALCULATION

Except when IPRINT = 1, a calculation of the volume enclosed by the blade between the innermost and outermost streamsurfaces is made. This is done from the Cartesian coordinates of the points describing the streamsurface blade sections. The total volume is obtained by summing the volumes enclosed between each adjacent pair of streamsurfaces. These volumes in turn are obtained by summing two types of sub-volume. First, there is the volume enclosed by the leading edge radius. This is determined by finding the mean area of the two leading edge semicircles on the two streamsurfaces, and multiplying by the mean height at the two ends of the semi-circle diameters. The diameter of the leading edge is calculated to be the distance between the first points on the section pressure and suction surfaces using the streamsurface Cartesian coordinates. Thus the areas computed are those projected onto a constant-z plane, and the volume is given directly by multiplying by the mean z dimension. Second, there is a series of volumes enclosed by corresponding quadrilaterals on the two streamsurfaces. Again, the sub-volume is determined from the mean of the areas of the two quadrilaterals projected onto a constant-z plane, and the mean distance between them. The quadrilaterals are each defined by two adjacent points on the section suction surface and the two corresponding points on the pressure surface. The area of the quadrilaterals is obtained by assuming them to be rectangles of side ℓ and m, as defined in Equations (96) and (97), except that in this case Cartesian coordinates of the streamsurface sections are used. The distance between the two rectangles is taken to be the mean of the distance between the four corresponding corners of the rectangle. Thus the total volume, V, is given by

$$V = \sum_{1,J-1} \left[(Z_{r_{j+1}} - Z_{r_j}) A_r + \sum_{1,N-1} \frac{(\ell_{n,j+1} m_{n,j+1} + \ell_{n,j} m_{n,j})(Z_{n_{j+1}} - Z_{n_j})}{2} \right] \tag{106}$$

where J is the total number of streamsurfaces, z_r is the mean coordinate at each end of the leading edge semicircle diameter, A_r is the mean of the two leading edge semicircle areas, N is the number of points defining each blade surface, and z_n is the mean z-coordinate at the four corners of the rectangle. Equation (106) is modified to contain a term similar to the first to represent the trailing edge contribution for the double-circular-arc blade.

2. CALCULATIONS FOR AERODYNAMIC ANALYSIS

Certain aerodynamic analyses of the blade require a description of the blade on cylindrical surfaces. As an option, the computer program will produce quantities necessary for this description at a specified streamsurface-computing station intersection.

First, the angular position of the camber line with respect to the stack axis at a streamsurface-computing station intersection is specified in terms of Φ, which is the value of $\varepsilon_{\text{camber line}}$ on the streamsurface at that particular intersection.

The physical passage blockage (b) due to the presence of the blades is determined as a percentage of the passage circumference in terms of the number of blades in the blade row, N, and σ, the angle subtended on the cylindrical surface by each blade.

$$b_b = \frac{N\sigma}{2\pi} \tag{107}$$

The blade lean angle, ϵ, with respect to the radial direction at a given point is obtained from the slope of a spline-curve fit through the y-z Cartesian coordinates of the streamsurface section camber lines at the particular axial location. Thus

$$\epsilon = \Phi - \text{Arctan}\left(\frac{dy}{dz}\right) \tag{108}$$

Two other quantities are needed to produce the proper mean-camber line angle on the cylindrical surface: the local computing station inclination, μ, obtained from the specified station description; and the local streamsurface inclination, γ, obtained from the specified r-x streamsurface description. Together with the camber line angle on the streamsurface, α_*^o:

$$\tan \alpha_*^o = \frac{\tan \gamma \tan \epsilon + \tan \alpha_* / \cos \gamma}{1 - \tan \mu \tan \gamma} \tag{109}$$

Equation (109) is taken from Reference 3.

SECTION VII

USE OF THE COMPUTER PROGRAM

Basic information required by the user to run the computer program is given in this section. The various input data items are defined first, and the input data format is then specified. A description of the output data that may be expected is given. (Implementation of the program on a computing system is not discussed here, but in the section entitled "Computer Program Details".)

1. DEFINITION OF INPUT DATA ITEMS

TITLE	An alphanumeric title of 72 characters that may be used to identify a run.
NLINES	The number of streamsurfaces which are defined on and on which blade sections will be designed. Must satisfy $2 \leq \text{NLINES} \leq 15$.
NSTNS	The number of computing stations at which the streamsurface radii are specified. Must satisfy $3 \leq \text{NSTNS} \leq 10$.
NZ	The number of constant-z planes on which manufacturing (Cartesian) coordinates for the blade are required. Must satisfy $3 \leq \text{NZ} \leq 15$.
NSPEC	The number of radially-disposed points at which the parameters of the blade sections are specified. Must satisfy $1 \leq \text{NSPEC} \leq 15$.
NPOINT	The number of points that will be generated to specify the pressure and suction surfaces of each blade section. Must satisfy $2 \leq \text{NPOINT} \leq 80$. Generally, no less than 30 should be used. It will be advantageous to specify 80 points when precision plots of the sections are to be produced directly by the program.
NBLADE	The number of blades in the blade row.
ISTAK	If ISTAK = 0, the blade will be stacked at the leading edge. If ISTAK = 1, the blade will be stacked at the trailing edge. If ISTAK = 2, the blade will be stacked at, or offset from, the section centroid.

IPUNCH — An integer which indicates whether the quantities necessary for aerodynamic analysis of the blade are to be produced on punched cards.

ISECN — If ISECN = 0, the blade will be constructed using the polynomial camber line and the standard thickness distribution.

If ISECN = 1, the exponential camber line and the standard thickness distribution will be used.

If ISECN = 2, a blade using the circular arc camber line and the double-circular-arc thickness distribution will be used.

If ISECN = 3, the standard thickness distribution and any of the camber lines described in the sub-section, "Multiple Circular-Arc Camber Lines," may be used.

IFCORD — If IFCORD = 0, the meridional projections of the streamsurface blade section chords are specified.

If IFCORD = 1, the streamsurface blade section chords are specified.

IFPLOT — Where CALCOMP software is incorporated into the computing system, IFPLOT specifies the creation of precision plots. (Further information regarding the requirements for this are given in the section entitled "Computer Program Details".)

If IFPLOT = 0, no plots will be produced.

If IFPLOT = 1, a plot of the streamsurface sections will be produced. All NLINES sections are shown superimposed. The origin for each section plot is offset from the centroid of the section by distances specified by DELX and DELY.

If IFPLOT = 2, a plot of the manufacturing sections will be produced. The origin is the blade stacking axis, and all NZ sections are shown superimposed.

If IFPLOT = 3, both of the plots described for IFPLOT = 1 and 2 will be produced.

	If IFPLOT = 4, individual plots of each of the manufacturing sections will be produced. The axes are rotated clockwise by the section stagger angle for each plot.
IPRINT	The input data is always listed by the program. Details of the streamsurface and manufacturing sections are printed as prescribed by IPRINT.
	If IPRINT = 0, details of streamsurface and manufacturing sections are printed.
	If IPRINT = 1, details of streamsurface sections are printed.
	If IPRINT = 2, details of the manufacturing sections are printed.
ZINNER, ZOUTER	The NZ manufacturing sections are equispaced between z equals ZINNER and ZOUTER.
SCALE	When precision plots are produced, SCALE is the scale factor employed.
STACKX	This is the axial coordinate of the stacking axis for the blade, relative to the same origin as used for the station locations, XSTA.
PLTSZE	The size (inches) of the plotter to be used in the creation of precision plots.
KPTS	The number of points provided to specify the shape of a computing station.
	If KPTS = 1, the computing station is upright and linear.
	If KPTS = 2, the computing station is linear and either upright or inclined.
	If KPTS > 2, a spline curve is fit through the points provided to specify the shape of the station.
IFANGS	If IFANGS = 0, the calculations of the quantities required for aerodynamic analysis will be omitted at a particular computing station.
	If IFANGS = 1, these calculations will be performed at that station.

XSTA — An array of KPTS axial coordinates (relative to an arbitrary origin) which, together with RSTA, specify the shape of a particular computing station.

RSTA — An array of KPTS radii which, together with XSTA, specify the shape of a particular computing station.

R — The streamsurface radii at NLINES locations at each of the NSTNS stations.

ZR — The variation of properties of the streamsurface blade sections is specified as a function of streamsurface number. The various quantities are then interpolated (or extrapolated) at each streamsurface. The streamsurfaces are numbered consecutively from the innermost outward, starting with 1.0. ZR must increase monotonically, there being NSPEC values in all.

B1 — The blade inlet angle. (Figure 17 illustrates the geometry of a typical blade section.)

B2 — The blade outlet angle.

PP — If ISECN = 0, PP is the ratio of the second derivative of the camber line at the leading edge to its maximum value. Must satisfy $-2.0 < PP < 1.0$.

If ISECN = 1, PP is the ratio of the second derivative of the camber line at the leading edge to its maximum value forward of the inflection point. Must satisfy $0.0 < PP \leq 1.0$.

If ISECN = 2 or 3, PP is superfluous.

QQ — If ISECN = 0, QQ is the ratio of the second derivative of the camber line at the trailing edge to its maximum value. Must satisfy $0.0 \leq QQ \leq 1.0$.

If ISECN = 1, QQ is the ratio of the second derivative of the camber line at the trailing edge to its maximum value rearward of the inflection point. Must satisfy $0.0 < QQ \leq 1.0$.

NOTE: Some comments regarding useful values for PP, QQ, S and BS are made in the section entitled "Examples of Use of Computer Program."

If ISECN = 2 or 3, QQ is superfluous.

RLE	The ratio of blade leading edge radius to chord.
TC	The ratio of blade maximum thickness to chord.
TE	The ratio of blade trailing edge half-thickness to chord. If ISECN = 2, TE is superfluous.
Z	The location of the blade maximum thickness, as a fraction of camber line length. If ISECN = 2, Z is superfluous.
CORD	If IFCORD = 0, CORD is the meridional projection of the blade chord. If IFCORD = 1, CORD is the blade chord.
DELX, DELY	The stacking axis passes through the stream-surface blade sections, offset from the centroids, leading, or trailing edge by DELX and DELY in the x and y directions respectively.
S, BS	If ISECN = 1 or 3, S and BS are used to specify the location of the inflection point (as a fraction of the meridionally-projected chord length) and the change in camber angle from the leading edge to the inflection point. If the absolute value of the angle at the inflection point is larger than the absolute value of B1, BS should have the same sign as B1; otherwise, B1 and BS should be of opposite sign.

2. INPUT DATA FORMAT

Data input is by punched card, and three formats are used. The first card only is alphanumeric, using the first 72 columns on the card. This is followed by one card of integers. Integers are each placed in a field of three locations, starting in Column 1 of the card. No decimal point may be used, and the number must occupy the right-most locations of the allocated field. Real numbers are each placed in fields of 12 locations, starting in Column 1 of the card. Decimal points should be included to ensure correct interpretation of the data, and the numbers may be placed anywhere in the allocated fields.

In the following chart, one line corresponds to one card.

TITLE

NLINES NSTNS NZ NSPEC NPOINT NBLADE ISTAK IPUNCH ISECN IFCORD IFPLOT IPRINT

ZINNER ZOUTER SCALE STACKX PLTSZE

KPTS IFANGS

XSTA RSTA	repeated KPTS times	repeated NSTNS times
R	repeated NLINES times	

ZR B1 B2 PP QQ RLE	repeated NSPEC times
TC TE Z CORD DELX DELY	
S BS - if ISECN = 1 or 3 only	

Listings of sample input data decks are included under "Examples of Use of Computer Program."

3. OUTPUT DATA

Printed output from the program may be considered to consist of four sections: a printout of the input data, details of the blade sections on each streamsurface, a listing of quantities required for aerodynamic analysis, and details of the manufacturing sections determined on the constant-z planes. These are briefly described below. In the explanation which follows, parenthetical statements are understood to refer to the particular case of the double-circular-arc blade (ISECN = 2).

The input data printout includes all quantities read in, and is self-explanatory.

Details of the streamsurface blade sections are printed if IPRINT = 0 or 1. Listed first are the parameters defining the blade section. These are interpolated at the streamsurface from the tables read in. Then follow details of the blade section in "normalized" form. The blade section geometry is given for the section specified, except that the meridional project of the chord is unity. For this section of the output, the coordinate origin is the blade leading edge. The following quantities are given: blade chord; stagger angle; camber angle; section area; location of centroid of the section; second moments of area of the section about the centroid; orientation of the principal axes; and the principal second moments of area of the section about the centroid. Then are listed the coordinates of the camber line, the camber line angle, the section thickness, and the coordinates of the blade surfaces. NPOINT values are given.

A lineprinter plot of the normalized section follows. The scales for the plot are arranged so that the section just fills the page, so that the scales will generally differ from one plot to another. "Dimensional" details of the blade section are given next. The normalized data given previously is scaled to give a blade section as defined by IFCORD and CORD. For this section of the output, the coordinates are with respect to the blade stacking axis. The following quantities are given: blade chord; radius and location of center of leading (and trailing) edge(s); section area; the second moments of area of the section about the centroid; and the principal second moments of area of the section about the centroid. The coordinates of NPOINT points on the blade surfaces are then listed, followed by the coordinates of 31 points distributed at (roughly) six degree intervals around the leading (and trailing) edges. Finally, the coordinates of the blade surfaces and points around the leading (and trailing) edge(s) is (are) shown in Cartesian form.

The quantities required for aerodynamic analysis are printed at all computing stations specified by the IFANGS parameter. The radius, section angle, blade lean angle, blade blockage, and relative angular location of the camber line are printed at each streamsurface intersection with the particular computing station.

Details of the manufacturing sections are printed if IPRINT = 0 or 2. At each value of z specified by ZINNER, ZOUTER and NZ, section properties and coordinates are given. The origin for the coordinates is the blade stacking axis. The following quantities are given: section area; the location of the centroid of the section; the second moments of area of the section about the centroid; the principal second moments of area of the section about the centroid; the orientation of the principal axes; and the section torsional constant. Then the coordinates of NPOINT points on the blade section surfaces are listed, followed by 31 points around the leading (and trailing) edge(s).

Precision plots are produced if IFPLOT = 1, 2, 3 or 4 as described under the definition of IFPLOT given previously.

If IPUNCH = 1, the program punches the quantities required for aerodynamic analysis, together with identifying indices denoting station number and streamsurface number, on cards in the following format: 5 fields each of 12 locations for the quantities themselves, followed by 2 fields each of 3 locations for the indices.

SECTION VIII

EXAMPLES OF USE OF THE PROGRAM

1. INTRODUCTION

This section shows the use of the program to generate four blades: one based upon the polynomial camber line; another upon the exponential camber line; a double-circular-arc blade; and one based upon the multiple-circular-arc camber line. The same basic aerodynamic design is assumed for the first two and last cases, although all blades could not satisfy the same aerodynamic requirements. Figure 18 is a meridional section through the compressor annulus, showing eight streamsurfaces (including the hub and casing) defining the flow, and the locations of six planes on which manufacturing sections are to be determined. Usually, more streamlines would be used to define the flow and thus the blade, by means of the streamsurface blade sections. Also, it would normally be advantageous to determine more than six manufacturing sections. However, these numbers were selected for the sample runs of the program as they exemplify the program adequately and lend clarity to the resulting figures. Included on Figure 18 are the approximate locations of the blade leading and trailing edges for the polynomial camber line case. The exponential and multiple-circular-arc camber line cases would appear slightly different for reasons discussed below.

2. POLYNOMIAL CAMBER LINE

a. Input Data

The input data deck used for this example is listed below. Some points of interest are noted in the order in which they occur in the input.

As mentioned previously, eight streamsurface blade sections are used to define the blade. The streamsurface radii are specified at eight locations, the first and last of which are outside, and well clear of, the rotor. This ensures that the boundary conditions imposed on the spline-curve (zero curvature at the end points) have little influence on the shape of the curve representing the streamsurface in the region of interest, that is, within the blade. The parameters defining the streamsurface blade sections are given at eight locations; that is, directly at each streamsurface. Thus the interpolation of the parameters at each streamsurface is reduced in this case to merely reading the appropriate row of data from the table. Fifty points are specified to define each blade surface. This number serves the purposes of this example well, but it would be advantageous to use more points where the precision-plot output is to be directly incorporated in the manufacturing

procedure. Specification of the meridionally-projected chord (rather than actual chord) is selected. All optional sections of the output are to be printed. Superimposed plots of the streamsurface and manufacturing sections are to be produced at a scale of five times full size.

Blade inlet and outlet angles would normally be determined from an aerodynamic analysis of the flow through the blade row. Desirable incidence angles for this profile type are probably near to one half the leading edge wedge angle. Considerations of static pressure (or velocity) distributions within the blade channel, and choking flow limits, will influence the selection of incidence angles, depending upon the selected aerodynamic analysis method. Deviation angles for the profile have not been empirically determined as yet, and therefore the best means of estimating deviation angles is probably to use Carter's Rule, or a similar formulation. Some consideration of the camber line shape (point of maximum camber, for example) should be made. The parameters PP and QQ are set to 0.0 and 0.5 on all streamsurfaces, respectively. It is anticipated that the zero curvature leading edge configuration (PP = 0.0) will be frequently specified for this profile type. The specification of a second derivative at the trailing edge that is less than its maximum value (QQ = 0.5) is made to prevent the curvature of the camber line from rising to a maximum at the trailing edge. It is believed that this could cause excessive deviation angles. The blade thickness distribution of a rotor blade is determined by aerodynamic and mechanical factors. The leading edge radius and trailing edge half-thickness are set to approximately .005 inch, which is probably a practical minimum. Maximum thickness/chord ratios specified vary from 4.8% at the hub to 3.1% at the casing. These figures are typical of those aerodynamically acceptable for a high Mach number rotor blade, and yield a blade with a reasonable distribution of cross-sectional area. The maximum thickness is placed at 0.6 of the camber line from the leading edge, which helps to maintain a small leading edge wedge angle.

FIGURE EXAMPLE BLADE DESIGN - POLYNOMIAL CAMBER LINE

```
  8   8   6   8 5. 3.   2   )   )   .   3   0
6.5          9.0          5.0          0.0          12.0
  1   0
-1.4357      0.0
6.623
6.9746
7.3197
7.6645
8.0126
8.3681
8.7351
9.12
  2   0
-1.5357      0.0
-1.0264      6.75
6.75
7.0669
7.3844
7.6994
8.0159
8.3365
8.5623
9.0
  1   1
-.5767       0.0
6.8864
7.1634
7.4420
7.7259
8.0169
8.3160
8.6233
8.9382
  1   1
-.2087       0.0
6.9372
7.2338
7.4849
7.7421
8.0067
8.2777
8.5558
8.8417
  1   1
.20063       0.0
7.0786
7.2950
7.5164
7.7436
```

7.977.					
8.2261					
8.4732					
8.7345					
1 1					
.0093	0.0				
7.1496					
7.3387					
7.5525					
7.7525					
7.9462					
8.1385					
8.3385					
8.5315					
2 .					
2..623	0.0				
1..269	7.2076				
7.2.76					
7.3759					
7.5496					
7.7561					
7.9189					
8.1197					
8.3377					
8.5845					
1 .					
1.4273	0.0				
7.2715					
7.4214					
7.5768					
7.7380					
7.9.54					
8..865					
8.2651					
8.4624					
1..	57.	8.3.9	0.0	0.5	.00175
.04357	.00175	0.6	2.1109		
2.0	58.954	12.614	0.0	0.5	.00171
.04636	.00171	0.6	2.0525		
3..	60.858	15.336	0.0	0.5	.00167
.04245	.00167	0.6	1.9940		
4..	62.685	19.965	0.0	0.5	.00163
..397	.00163	0.6	1.9356		
5..	64.348	23.758	0.0	0.5	.00159
..373.	.00159	0.6	1.8771		
6..	65.623	28.327	0.0	0.5	.00155
..3463	.00155	0.5	1.8187		
7..	66.471	34.37	0.0	0.5	.00153
..3317	.00153	0.6	1.7603		
8..	67.1	42.52	0.0	0.5	.00150
..3.29	..015.	0.6	1.7018		

b. Output Data

The input data specified all optional output data, and a selection for each section of the output is shown below. Some points of interest are as follows.

Shown first is the printout of the input data; all input items are listed. This is followed by details of the first streamsurface blade section. The parameters defining the blade section are followed by details of, and a line-printer plot of, the normalized blade section. Then appears a specification of the section scaled to the desired dimensions. First there are the fifty points specified for each blade surface. These are printed two per line, and if an odd number of points is specified, coordinates of the last point are not printed. Next follow the coordinates of the 31 points describing the leading edge radius. The final data for the streamsurface section are the equivalent Cartesian coordinates for the points just mentioned. It will be seen that the first and last points on the leading edge radius coincide with the first points on the pressure and suction surfaces.

The same format is repeated for each of the remaining streamsurface blade sections, and a printout of the volume enclosed by the blade, but these results have not been reproduced here. The calculations for aerodynamic analysis are printed next for those computing stations for which they were requested by the IFANGS parameter, presented in order of increasing radial streamsurface location.

Details of the six manufacturing sections defining the blade follow. Reproduced below is the output relating to the first (innermost) section. Properties of the section are followed by the coordinates of 50 points on each blade surface, and 31 points around the leading edge. It will be noted that the section centroid is not calculated to be exactly on the stacking axis (the origin for the coordinates) although the offsets DELX and DELY were all zero. This is a reflection of the fact that the streamsurface sections is not planar. If it were desired to have the centroids of the manufacturing sections lie precisely on the stacking axis, the program would be rerun with DELX and DELY offsets specified so that they counteract the mislocation of the centroids previously determined. This iterative procedure might require more than one loop, depending upon the accuracy desired. Use of the centroid offsets alo permits the final blade to be leaned for stress redistribution or other purposes.

The input data specified superimposed precision plots of both the streamsurface sections and manufacturing sections. These plots are reproduced (at reduced size) as Figures 19 and

20, respectively. It is of interest to refer also to Figure 18. The innermost manufacturing plane is well below the lowest point on the hub streamsurface section in the plane of the stacking axis, that is, the plane of Figure 18. The Cartesian coordinates of the first streamsurface blade section show that the lowest point on the section (the 20th point on the leading edge) is at $z = 6.66478$. The radius of the streamsurface at this point is 6.75 (approximately), and the innermost manufacturing plane is at $z = 6.5$. Thus, at the leading edge the extrapolation required to define the manufacturing section is somewhat smaller than might at first appear. At the trailing edge, extrapolation is required to define the first two manufacturing sections. The streamsurface radius at the casing and z-coordinate for the outermost manufacturing plane both equal 9.0 at the blade inlet. However, the z-coordinate of the leading edge of the blade is 8.8357, so that the outermost manufacturing section too is defined completely by extrapolation. Of course, portions of the blade that are defined by extrapolation would not appear on a final blade, but would facilitate manufacture.

```
                                        USAF - ARL(ARF)  HIGH MACH NUMBER COMPRESSOR BLADE PROGRAM
                                        **********************************************************
TITLE                             =          FIGURE      EXAMPLE BLADE DESIGN - POLYNOMIAL CAMBER LINE
NUMBER OF STREAMSURFACES          =  8
NUMBER OF STATIONS                =  8
NUMBER OF CONSTANT-Z PLANES       =  6
NUMBER OF BLADE DATA POINTS       =  8
NUMBER OF POINTS ON SURFACES      = 50
NUMBER OF BLADES IN BLADE ROW     = 30
ISTAK                             =  2
IFUNCH                            =  0
ISECN                             =  0
IFCORD                            =  0
IFPLOT                            =  3
IPRINT                            =  0

ZINNER                            =  6.5000
ZOUTER                            =  9.0000
SCALE                             =  2.5000
STACKX                            =  0.0000
PLTSZE                            = 12.0000

          STREAMSURFACE GEOMETRY SPECIFICATION

   COMPUTING STATION  1     NUMBER OF DESCRIBING POINTS=  2      IFANGS( 1)=  0

DESCRIPTION           STREAMLINE     RADII
 X          R           NUMBER

-1.4357    0.0000          1          6.6230
-1.4357    1.0000          2          6.9746
                           3          7.3197
                           4          7.6645
                           5          8.0126
                           6          8.3681
                           7          8.7350
                           8          9.1200

   COMPUTING STATION  2     NUMBER OF DESCRIBING POINTS=  2      IFANGS( 2)=  0

DESCRIPTION           STREAMLINE     RADII
 X          R           NUMBER

-1.6357    0.0000          1          6.7500
-1.0264    6.7500          2          7.0689
                           3          7.3844
                           4          7.6994
                           5          8.0159
                           6          8.3365
                           7          8.6629
                           8          9.0000
```

COMPUTING STATION 3 NUMBER OF DESCRIBING POINTS= 2 IFANGS(3)= 1

DESCRIPTION X	R	STREAMLINE NUMBER	RADII
-.5767	0.0000	1	6.8864
-.5767	1.0000	2	7.1634
		3	7.4429
		4	7.7259
		5	8.0169
		6	8.3160
		7	8.6237
		8	8.9382

COMPUTING STATION 4 NUMBER OF DESCRIBING POINTS= 2 IFANGS(4)= 1

DESCRIPTION X	R	STREAMLINE NUMBER	RADII
-.2087	0.0000	1	6.9872
-.2087	1.0000	2	7.2339
		3	7.4849
		4	7.7421
		5	8.0063
		6	8.2777
		7	8.5558
		8	8.8417

COMPUTING STATION 5 NUMBER OF DESCRIBING POINTS= 2 IFANGS(5)= 1

DESCRIPTION X	R	STREAMLINE NUMBER	RADII
.2000	0.0000	1	7.0786
.2000	1.0000	2	7.2950
		3	7.5164
		4	7.7436
		5	7.9770
		6	8.2201
		7	8.4732
		8	8.7345

COMPUTING STATION 6 NUMBER OF DESCRIBING POINTS= 2 IFANGS(6)= 1

DESCRIPTION X	R	STREAMLINE NUMBER	RADII
.6093	0.0000	1	7.1496
.6093	1.0000	2	7.3387
		3	7.5325
		4	7.7325
		5	7.9403
		6	8.1583
		7	8.3885
		8	8.6315

COMPUTING STATION 7 NUMBER OF DESCRIBING POINTS= 2 IFANGS(7)= 0

DESCRIPTION X	R	STREAMLINE NUMBER	RADII
2.0623	0.0000	1	7.2076
1.0269	7.2076	2	7.3759
		3	7.5496
		4	7.7301
		5	7.9189
		6	8.1197
		7	8.3377
		8	8.5846

COMPUTING STATION 8 NUMBER OF DESCRIBING POINTS= 2 IFANGS(8)= 0

DESCRIPTION X	R	STREAMLINE NUMBER	RADII
1.4273	0.0000	1	7.2715
1.4273	1.0000	2	7.4214
		3	7.5768
		4	7.7380
		5	7.9054
		6	8.0805
		7	8.2651
		8	8.4624

SECTION GEOMETRY SPECIFICATION

STREAMLINE NUMBER	INLET ANGLE	OUTLET ANGLE	Y2 LE/ MAX VALUE	Y2 TE/ MAX VALUE	LE RADIUS /CHORD	MAX THICK /CHORD	TE THICK /2*CHORD	POINT OF MAX THICK	CHORD OR AXIAL CD	X STACK OFFSET	Y STACK OFFSET
1.00	57.000	8.809	0.0000	.5000	.00175	.04857	.00175	.6000	2.1109	-0.000000	-0.000000
2.00	58.954	12.614	0.0000	.5000	.00171	.04536	.00171	.6000	2.0525	-0.000000	-0.000000
3.00	60.858	16.336	0.0000	.5000	.00167	.04243	.00167	.6000	1.9940	-0.000000	-0.000000
4.00	62.686	19.965	0.0000	.5000	.00163	.03970	.00163	.6000	1.9356	-0.000000	-0.000000
5.00	64.348	23.758	0.0000	.5000	.00159	.03731	.00159	.6000	1.8771	-0.000000	-0.000000
6.00	65.623	28.327	0.0000	.5000	.00155	.03503	.00155	.6000	1.8187	-0.000000	-0.000000
7.00	66.471	34.370	0.0000	.5000	.00153	.03317	.00153	.6000	1.7603	-0.000000	-0.000000
8.00	67.100	42.520	0.0000	.5000	.00150	.03129	.00150	.6000	1.7018	-0.000000	-0.000000

STREAMSURFACE GEOMETRY ON STREAMLINE NUMBER 1

```
F              = 0.0000     (D2YDX2 OF MEANLINE AT LEADING EDGE AS A FRACTION OF ITS MAXIMUM VALUE.)
G              =  .5000     (D2YDX2 OF MEANLINE AT TRAILING EDGE AS A FRACTION OF ITS MAXIMUM VALUE.)
BETA1          = 57.000     (BLADE INLET ANGLE.)
BETA2          =  8.809     (BLADE OUTLET ANGLE.)
YZERO          =  .00175    (BLADE LEADING EDGE RADIUS AS A FRACTION OF CHORD.)
T              =  .04857    (BLADE MAXIMUM THICKNESS AS A FRACTION OF CHORD.)
YONE           =  .00175    (BLADE TRAILING EDGE HALF-THICKNESS AS A FRACTION OF CHORD.)
Z              =  .6000     (LOCATION OF MAXIMUM THICKNESS AS A FRACTION OF MEAN LINE.)
CORD           = 2.1109     (CHORD OR MERIDIONAL CHORD OF SECTION.)
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NORMALISED RESULTS - ALL THE FOLLOWING REFER TO A BLADE HAVING A MERIDIONAL CHORD PROJECTION OF UNITY
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BLADE CHORD      = 1.3614

STAGGER ANGLE    = 42.727

CAMBER ANGLE     = 48.191

SECTION AREA     = .06290

LOCATION OF CENTROID RELATIVE TO LEADING EDGE

         XBAR =  .46746
         YBAR =  .58491

SECOND MOMENTS OF AREA ABOUT CENTROID

         IX   =  .00323
         IY   =  .00325
         IXY  =  .00316

ANGLE OF INCLINATION OF (ONE) PRINCIPAL AXIS TO 'X' AXIS = 44.901

PRINCIPAL SECOND MOMENTS OF AREA ABOUT CENTROID

         IPX  = .00009     (AT 44.901 WITH 'X' AXIS)
         IPY  = .00640     (AT 44.901 WITH 'Y' AXIS)
```
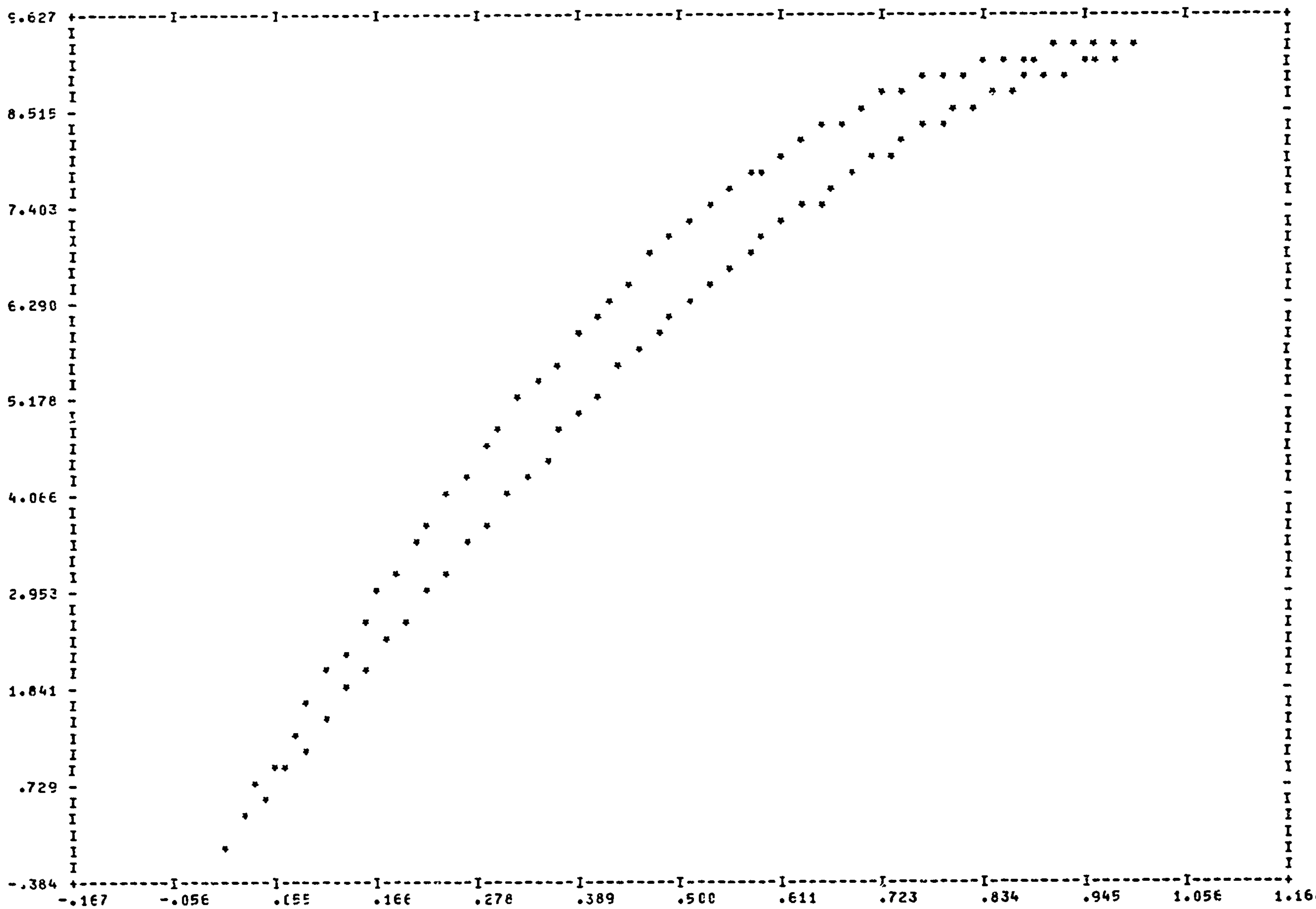

POINT NUMBER	MEANLINE DATA X	Y	ANGLE	THICKNESS	SURFACE COORDINATE DATA XS	YS	XP	YP
1	.00238	0.00000	57.000	.00477	.00038	.00130	.00438	-.00130
2	.02273	.03133	56.978	.00885	.01903	.03374	.02644	.02892
3	.04309	.06261	56.911	.01290	.03768	.06613	.04849	.05909
4	.06344	.09378	56.801	.01692	.05636	.09841	.07052	.08915
5	.08379	.12480	56.650	.02088	.07507	.13054	.09251	.11906
6	.10414	.15561	56.457	.02475	.09383	.16245	.11446	.14877
7	.12450	.18618	56.222	.02853	.11264	.19411	.13635	.17825
8	.14485	.21645	55.947	.03219	.13151	.22546	.15818	.20744
9	.16520	.24639	55.631	.03572	.15046	.25647	.17994	.23631
10	.18555	.27596	55.274	.03910	.16949	.28709	.20162	.26482
11	.20590	.30511	54.876	.04231	.18860	.31728	.22321	.29293
12	.22626	.33381	54.435	.04536	.20781	.34700	.24470	.32062
13	.24661	.36202	53.953	.04822	.22712	.37621	.26610	.34784
14	.26696	.38972	53.427	.05088	.24653	.40488	.28739	.37457
15	.28731	.41688	52.857	.05334	.26605	.43298	.30857	.40077

POINT NUMBER	MEANLINE DATA X	Y	ANGLE	THICKNESS	SURFACE COORDINATE DATA XS	YS	XP	YP
16	.30766	.44345	52.243	.05560	.28569	.46047	.32964	.42643
17	.32802	.46942	51.583	.05764	.30544	.48733	.35060	.45152
18	.34837	.49477	50.876	.05946	.32531	.51353	.37143	.47601
19	.36872	.51946	50.121	.06106	.34529	.53903	.39215	.49988
20	.38907	.54348	49.317	.06244	.36540	.56383	.41275	.52313
21	.40942	.56681	48.464	.06360	.38562	.58789	.43323	.54572
22	.42978	.58942	47.559	.06453	.40596	.61120	.45359	.56765
23	.45013	.61131	46.603	.06525	.42642	.63373	.47383	.58890
24	.47048	.63247	45.594	.06575	.44699	.65547	.49397	.60946
25	.49083	.65287	44.533	.06604	.46767	.67641	.51399	.62933
26	.51118	.67251	43.417	.06612	.48846	.69652	.53391	.64849
27	.53154	.69138	42.249	.06600	.50935	.71581	.55372	.66695
28	.55189	.70948	41.027	.06567	.53034	.73425	.57344	.68471
29	.57224	.72680	39.752	.06512	.55142	.75183	.59306	.70176
30	.59259	.74333	38.427	.06437	.57259	.76855	.61260	.71812
31	.61295	.75909	37.052	.06340	.59384	.78439	.63205	.73379
32	.63330	.77406	35.629	.06223	.61517	.79935	.65142	.74877
33	.65365	.78826	34.163	.06084	.63657	.81344	.67073	.76309
34	.67400	.80169	32.656	.05925	.65802	.82663	.68999	.77675
35	.69435	.81435	31.114	.05745	.67951	.83894	.70920	.78976
36	.71471	.82626	29.541	.05544	.70104	.85038	.72837	.80215
37	.73506	.83743	27.945	.05322	.72259	.86093	.74753	.81392
38	.75541	.84786	26.330	.05080	.74414	.87062	.76668	.82510
39	.77576	.85758	24.706	.04816	.76570	.87945	.78583	.83570
40	.79611	.86659	23.081	.04532	.78723	.88744	.80500	.84574
41	.81647	.87493	21.463	.04227	.80873	.89460	.82420	.85526
42	.83682	.88260	19.862	.03901	.83019	.90095	.84345	.86426
43	.85717	.88964	18.287	.03553	.85160	.90651	.86275	.87277
44	.87752	.89606	16.748	.03184	.87294	.91130	.88211	.88082
45	.89787	.90190	15.255	.02791	.89420	.91536	.90155	.88843
46	.91823	.90717	13.818	.02376	.91539	.91871	.92106	.89563
47	.93858	.91192	12.445	.01938	.93649	.92138	.94067	.90246
48	.95893	.91617	11.147	.01476	.95750	.92341	.96036	.90893
49	.97928	.91995	9.932	.00989	.97843	.92482	.98014	.91508
50	.99964	.92331	8.809	.00477	.99927	.92566	1.00000	.92095

NORMALISED PLOT OF SECTION NUMBER 1

SCALES - 'X' IS SHOWN TIMES 10 TO THE POWER OF -0 'Y' IS SHOWN TIMES 10 TO THE POWER OF 1



DIMENSIONAL RESULTS - ALL RESULTS REFER TO A BLADE OF SPECIFIED CHORD
****

BLADE CHORD = 2.87384E+00

L.E.RADIUS = 5.02922E-03 CENTERED AT X= -9.81728E-01 Y= -1.23469E+00

SECTION AREA = 2.80275E-01

SECOND MOMENTS OF AREA ABOUT CENTROID

IX = 6.41775E-02
IY = 6.46127E-02
IXY = 6.27008E-02

PRINCIPAL SECOND MOMENTS OF AREA ABOUT CENTROID

IFX = 1.69398E-03 (AT 44.901 WITH 'X' AXIS)
IFY = 1.27096E-01 (AT 44.901 WITH 'Y' AXIS)

PT NO	SUCTION------SURFACE X	Y	PRESSURE-----SURFACE X	Y	PT NO	SUCTION------SURFACE X	Y	PRESSURE-----SURFACE X	Y
1	-9.85946E-01	-1.23199E+00	-9.77510E-01	-1.23743E+00	2	-9.46594E-01	-1.16346E+00	-9.30939E-01	-1.17364E+00
3	-9.07217E-01	-1.09509E+00	-8.84399E-01	-1.10997E+00	4	-8.67790E-01	-1.02695E+00	-8.37899E-01	-1.04651E+00
5	-8.28291E-01	-9.59139E-01	-7.91476E-01	-9.83368E-01	6	-7.88698E-01	-8.91770E-01	-7.45146E-01	-9.20644E-01
7	-7.48990E-01	-8.24943E-01	-6.98931E-01	-8.58426E-01	8	-7.09149E-01	-7.58755E-01	-6.52850E-01	-7.96804E-01
9	-6.69155E-01	-6.93300E-01	-6.06922E-01	-7.35862E-01	10	-6.28991E-01	-6.28668E-01	-5.61163E-01	-6.75681E-01
11	-5.88644E-01	-5.64944E-01	-5.15988E-01	-6.16335E-01	12	-5.48097E-01	-5.02211E-01	-4.70212E-01	-5.57898E-01
13	-5.07339E-01	-4.40545E-01	-4.25047E-01	-5.00438E-01	14	-4.66360E-01	-3.80022E-01	-3.80104E-01	-4.44018E-01
15	-4.25150E-01	-3.20709E-01	-3.35391E-01	-3.88699E-01	16	-3.83702E-01	-2.62675E-01	-2.90917E-01	-3.34536E-01
17	-3.42011E-01	-2.05981E-01	-2.46686E-01	-2.81581E-01	18	-3.00071E-01	-1.50684E-01	-2.02703E-01	-2.29882E-01
19	-2.57881E-01	-9.68408E-02	-1.58971E-01	-1.79481E-01	20	-2.15439E-01	-4.45004E-02	-1.15490E-01	-1.30418E-01
21	-1.72747E-01	6.28975E-03	-7.22597E-02	-8.27279E-02	22	-1.29807E-01	5.54865E-02	-2.92774E-02	-3.64410E-02
23	-8.66224E-02	1.03050E-01	1.34605E-02	8.41644E-03	24	-4.31990E-02	1.48945E-01	5.59595E-02	5.18226E-02
25	4.56544E-04	1.93139E-01	9.82265E-02	9.37601E-02	26	4.43356E-02	2.35602E-01	1.40270E-01	1.34216E-01
27	8.84297E-02	2.76310E-01	1.82098E-01	1.73183E-01	28	1.32732E-01	3.15233E-01	2.23719E-01	2.10663E-01
29	1.77234E-01	3.52349E-01	2.65139E-01	2.46662E-01	30	2.21923E-01	3.87637E-01	3.06372E-01	2.81191E-01
31	2.66788E-01	4.21081E-01	3.47430E-01	3.14264E-01	32	3.11809E-01	4.52669E-01	3.88331E-01	3.45900E-01
33	3.56970E-01	4.82393E-01	4.29093E-01	3.76120E-01	34	4.02249E-01	5.10250E-01	4.69736E-01	4.04951E-01
35	4.47623E-01	5.36241E-01	5.10285E-01	4.32421E-01	36	4.93066E-01	5.60372E-01	5.50764E-01	4.58564E-01
37	5.38554E-01	5.82655E-01	5.91199E-01	4.83413E-01	38	5.84058E-01	6.03107E-01	6.31617E-01	5.07007E-01
39	6.29551E-01	6.21749E-01	6.72046E-01	5.29386E-01	40	6.75006E-01	6.38609E-01	7.12514E-01	5.50593E-01
41	7.20395E-01	6.53720E-01	7.53047E-01	5.70673E-01	42	7.65693E-01	6.67123E-01	7.93672E-01	5.89674E-01
43	8.10876E-01	6.78861E-01	8.34411E-01	6.07644E-01	44	8.55923E-01	6.88986E-01	8.75287E-01	6.24636E-01
45	9.00814E-01	6.97552E-01	9.16318E-01	6.40704E-01	46	9.45537E-01	7.04621E-01	9.57518E-01	6.55908E-01
47	9.90080E-01	7.10258E-01	9.98897E-01	6.70308E-01	48	1.03444E+00	7.14532E-01	1.04046E+00	6.83968E-01
49	1.07861E+00	7.17518E-01	1.08221E+00	6.96958E-01	50	1.12260E+00	7.19291E-01	1.12414E+00	7.09352E-01

POINTS DESCRIBING LEADING EDGE RADIUS

POINT NO.	X	Y
1	-9.77510E-01	-1.23743E+00
2	-9.77820E-01	-1.23785E+00
3	-9.78172E-01	-1.23824E+00
4	-9.78563E-01	-1.23860E+00
5	-9.78989E-01	-1.23891E+00
6	-9.79445E-01	-1.23917E+00
7	-9.79926E-01	-1.23938E+00
8	-9.80427E-01	-1.23955E+00
9	-9.80941E-01	-1.23966E+00
10	-9.81465E-01	-1.23971E+00
11	-9.81991E-01	-1.23971E+00
12	-9.82515E-01	-1.23966E+00
13	-9.83030E-01	-1.23955E+00
14	-9.83530E-01	-1.23938E+00
15	-9.84011E-01	-1.23917E+00
16	-9.84467E-01	-1.23891E+00
17	-9.84893E-01	-1.23860E+00
18	-9.85284E-01	-1.23824E+00
19	-9.85637E-01	-1.23785E+00
20	-9.85946E-01	-1.23743E+00
21	-9.86209E-01	-1.23697E+00
22	-9.86423E-01	-1.23649E+00
23	-9.86586E-01	-1.23599E+00
24	-9.86695E-01	-1.23547E+00
25	-9.86751E-01	-1.23495E+00
26	-9.86751E-01	-1.23442E+00
27	-9.86695E-01	-1.23390E+00
28	-9.86586E-01	-1.23339E+00
29	-9.86423E-01	-1.23289E+00
30	-9.86209E-01	-1.23240E+00
31	-9.85946E-01	-1.23195E+00

CARTESIAN COORDINATES ON STREAMSURFACE 1

POINT NO	ZS	XS	YS	ZP	XP	YP
1	6.66576E+00	-9.49930E-01	-1.20416E+00	6.66723E+00	-9.41869E-01	-1.20999E+00
2	6.68901E+00	-9.12325E-01	-1.13873E+00	6.69183E+00	-8.97362E-01	-1.14954E+00
3	6.71156E+00	-8.74687E-01	-1.07320E+00	6.71580E+00	-8.52868E-01	-1.08894E+00
4	6.73339E+00	-8.36990E-01	-1.00767E+00	6.73910E+00	-8.08403E-01	-1.02831E+00
5	6.75450E+00	-7.99213E-01	-9.42272E-01	6.76170E+00	-7.63986E-01	-9.67761E-01
6	6.77487E+00	-7.61328E-01	-8.77112E-01	6.78358E+00	-7.19635E-01	-9.07384E-01
7	6.79451E+00	-7.23316E-01	-8.12301E-01	6.80472E+00	-6.75365E-01	-8.47283E-01
8	6.81341E+00	-6.85156E-01	-7.47944E-01	6.82510E+00	-6.31193E-01	-7.87556E-01
9	6.83159E+00	-6.46826E-01	-6.84140E-01	6.84471E+00	-5.87131E-01	-7.28296E-01
10	6.84904E+00	-6.08308E-01	-6.21007E-01	6.86355E+00	-5.43196E-01	-6.69595E-01
11	6.86579E+00	-5.69587E-01	-5.58615E-01	6.88161E+00	-4.99394E-01	-6.11541E-01
12	6.88184E+00	-5.30642E-01	-4.97064E-01	6.89889E+00	-4.55741E-01	-5.54217E-01
13	6.89720E+00	-4.91462E-01	-4.36438E-01	6.91538E+00	-4.12240E-01	-4.97701E-01
14	6.91189E+00	-4.52034E-01	-3.76820E-01	6.93109E+00	-3.68904E-01	-4.42069E-01
15	6.92593E+00	-4.12339E-01	-3.18287E-01	6.94603E+00	-3.25733E-01	-3.87393E-01
16	6.93932E+00	-3.72375E-01	-2.60915E-01	6.96020E+00	-2.82739E-01	-3.33740E-01
17	6.95209E+00	-3.32129E-01	-2.04771E-01	6.97361E+00	-2.39918E-01	-2.81174E-01

POINT NO	ZS	XS	YS	ZP	XP	YP
18	6.96426E+00	-2.91592E-01	-1.49922E-01	6.98629E+00	-1.97279E-01	-2.29754E-01
19	6.97583E+00	-2.50764E-01	-9.64295E-02	6.99824E+00	-1.54820E-01	-1.79534E-01
20	6.98683E+00	-2.09631E-01	-4.43515E-02	7.00950E+00	-1.12548E-01	-1.30565E-01
21	6.99726E+00	-1.68202E-01	6.25846E-03	7.02011E+00	-7.04632E-02	-8.28905E-02
22	7.00717E+00	-1.26473E-01	5.53501E-02	7.03010E+00	-2.85665E-02	-3.65514E-02
23	7.01659E+00	-8.44509E-02	1.02877E-01	7.03952E+00	1.31397E-02	8.41793E-03
24	7.02554E+00	-4.21427E-02	1.48798E-01	7.04839E+00	5.46637E-02	5.19882E-02
25	7.03406E+00	4.45586E-04	1.93075E-01	7.05675E+00	9.60020E-02	9.41350E-02
26	7.04218E+00	4.33010E-02	2.35674E-01	7.06465E+00	1.37169E-01	1.34839E-01
27	7.04994E+00	8.64181E-02	2.76562E-01	7.07210E+00	1.78163E-01	1.74088E-01
28	7.05736E+00	1.29784E-01	3.15710E-01	7.07916E+00	2.18992E-01	2.11879E-01
29	7.06447E+00	1.73394E-01	3.53089E-01	7.08584E+00	2.59663E-01	2.48213E-01
30	7.07131E+00	2.17230E-01	3.88674E-01	7.09218E+00	3.00182E-01	2.83096E-01
31	7.07790E+00	2.61282E-01	4.22446E-01	7.09819E+00	3.40569E-01	3.16541E-01
32	7.08426E+00	3.05530E-01	4.54390E-01	7.10390E+00	3.80831E-01	3.48560E-01
33	7.09040E+00	3.49957E-01	4.84495E-01	7.10933E+00	4.20990E-01	3.79175E-01
34	7.09635E+00	3.94540E-01	5.12752E-01	7.11450E+00	4.61065E-01	4.08408E-01
35	7.10211E+00	4.39256E-01	5.39161E-01	7.11944E+00	5.01074E-01	4.36286E-01
36	7.10770E+00	4.84082E-01	5.63726E-01	7.12415E+00	5.41048E-01	4.62839E-01
37	7.11313E+00	5.28986E-01	5.86453E-01	7.12865E+00	5.81005E-01	4.88101E-01
38	7.11840E+00	5.73947E-01	6.07358E-01	7.13297E+00	6.20973E-01	5.12107E-01
39	7.12353E+00	6.18930E-01	6.26459E-01	7.13711E+00	6.60979E-01	5.34897E-01
40	7.12854E+00	6.63909E-01	6.43782E-01	7.14114E+00	7.01043E-01	5.56516E-01
41	7.13347E+00	7.08848E-01	6.59363E-01	7.14508E+00	7.41189E-01	5.77011E-01
42	7.13839E+00	7.53717E-01	6.73243E-01	7.14899E+00	7.81436E-01	5.96431E-01
43	7.14332E+00	7.98484E-01	6.85469E-01	7.15290E+00	8.21805E-01	6.14829E-01
44	7.14834E+00	8.43122E-01	6.96095E-01	7.15687E+00	8.62313E-01	6.32261E-01
45	7.15349E+00	8.87609E-01	7.05182E-01	7.16092E+00	9.02973E-01	6.48784E-01
46	7.15881E+00	9.31924E-01	7.12791E-01	7.16510E+00	9.43794E-01	6.64459E-01
47	7.16439E+00	9.76050E-01	7.18992E-01	7.16946E+00	9.84783E-01	6.79351E-01
48	7.17015E+00	1.01998E+00	7.23858E-01	7.17402E+00	1.02594E+00	6.93528E-01
49	7.17624E+00	1.06370E+00	7.27465E-01	7.17881E+00	1.06726E+00	7.07061E-01
50	7.18260E+00	1.10722E+00	7.29862E-01	7.18383E+00	1.10874E+00	7.20016E-01

POINT NO	ZSEMI	XSEMI	YSEMI
1	6.66723E+00	-9.41869E-01	-1.20999E+00
2	6.66706E+00	-9.42165E-01	-1.21039E+00
3	6.66689E+00	-9.42501E-01	-1.21076E+00
4	6.56671E+00	-9.42875E-01	-1.21109E+00
5	6. 6654E+00	-9.43282E-01	-1.21137E+00
6	6. 6636E+00	-9.43716E-01	-1.21160E+00
7	6.66618E+00	-9.44177E-01	-1.21179E+00
8	6.66600E+00	-9.44656E-01	-1.21192E+00
9	6.66584E+00	-9.45148E-01	-1.21200E+00
10	6.66567E+00	-9.45648E-01	-1.21203E+00
11	6.66552E+00	-9.46151E-01	-1.21200E+00
12	6.66536E+00	-9.46651E-01	-1.21192E+00
13	6.66525E+00	-9.47143E-01	-1.21179E+00
14	6.66513E+00	-9.47622E-01	-1.21160E+00
15	6.66503E+00	-9.48081E-01	-1.21136E+00
16	6.66495E+00	-9.48517E-01	-1.21108E+00
17	6.66488E+00	-9.48924E-01	-1.21075E+00
18	6.66483E+00	-9.49297E-01	-1.21039E+00
19	6.66480E+00	-9.49634E-01	-1.20998E+00
20	6.66478E+00	-9.49930E-01	-1.20955E+00
21	6.66479E+00	-9.50181E-01	-1.20908E+00
22	6.66481E+00	-9.50386E-01	-1.20860E+00

POINT NO	ZSEMI	XSEMI	YSEMI
23	6.66485E+00	-9.50541E-01	-1.20810E+00
24	6.66491E+00	-9.50646E-01	-1.20758E+00
25	6.66499E+00	-9.50698E-01	-1.20707E+00
26	6.66508E+00	-9.50698E-01	-1.20655E+00
27	6.66519E+00	-9.50646E-01	-1.20604E+00
28	6.66532E+00	-9.50541E-01	-1.20554E+00
29	6.66545E+00	-9.50386E-01	-1.20505E+00
30	6.66560E+00	-9.50181E-01	-1.20459E+00
31	6.66576E+00	-9.49930E-01	-1.20416E+00

BLADE CALCULATIONS FOR AERODYNAMIC ANALYSIS
****

STATION 3 NUMBER OF RADII= 8

RADIUS	SECTION ANGLE	LEAN ANGLE	BLADE BLOCKAGE	THETA
6.8864	56.8778	5.7310	.1005	-.0941
7.1634	58.4710	7.3291	.0955	-.0986
7.4420	60.1380	8.6890	.0909	-.1040
7.7259	61.8545	9.8866	.0858	-.1101
8.0169	63.5241	9.9633	.0805	-.1167
8.3160	64.9430	8.3483	.0737	-.1226
8.6233	66.0459	7.9518	.0666	-.1276
8.9382	67.0373	9.3307	.0602	-.1331

STATION 4 NUMBER OF RADII= 8

RADIUS	SECTION ANGLE	LEAN ANGLE	BLADE BLOCKAGE	THETA
6.9872	51.4198	3.3368	.1369	-.0208
7.2338	53.4525	3.6562	.1332	-.0229
7.4849	55.5857	3.9569	.1303	-.0252
7.7421	57.7541	4.3073	.1282	-.0276
8.0063	59.8658	4.5293	.1266	-.0302
8.2777	61.6934	4.3672	.1231	-.0328
8.5558	63.1635	4.8712	.1191	-.0354
8.8417	64.4945	6.2324	.1155	-.0386

STATION 5 NUMBER OF RADII= 8

RADIUS	SECTION ANGLE	LEAN ANGLE	BLADE BLOCKAGE	THETA
7.0786	40.5336	-2.3294	.1218	.0405
7.2950	43.4614	-2.7033	.1182	.0418
7.5164	46.3585	-3.1074	.1154	.0433
7.7436	49.2142	-3.4833	.1131	[illegible]
7.9770	51.9301	-3.1307	.1111	[illegible]
8.2201	54.2546	-1.7494	.1187	.0491
8.4732	56.3395	-1.0121	.1163	[illegible]
8.7345	58.8091	-1.3052	.1055	[illegible]

STATION 6 NUMBER OF RADII 8

RADIUS	SECTION ANGLE	LEAN ANGLE	PLACE BLOCKAGE	THETA
7.1496	24.8436	-10.6415	.0786	.3732
7.3387	28.7266	-10.8117	.0742	.3841
7.5325	32.3867	-11.1865	.0711	.0832
7.7325	35.8626	-11.5120	.0660	.3444
7.9403	39.0376	-10.7726	.0621	.0957
8.1583	42.0828	-8.8451	.0577	.1744
8.3885	45.7657	-10.1647	.0541	.1888
8.6315	50.6620	-14.8480	.0518	.1152

BLADE.SURFACE.GEOMETRY.IN.CARTESIAN.COORDINATES.AT.SPECIFIED.VALUES.OF.'Z'

SECTION NUMBER 1 'Z' = 6.5000

SECTION PROPERTIES

SECTION AREA		=	2.9390E-01	
LOCATION OF CENTROID	XBAR	=	4.7859E-02	
RELATIVE TO STACK AXIS	YBAR	=	-4.0183E-03	
SECOND MOMENTS OF AREA	IX	=	4.6612E-02	
ABOUT CENTROID	IY	=	7.2664E-02	
	IXY	=	5.4672E-02	
PRINCIPAL SECOND MOMENTS	IPX	=	3.4360E-03	(AT 38.30 DEGREES TO 'X' AXIS)
OF AREA ABOUT CENTROID	IPY	=	1.1584E-01	(AT 38.30 DEGREES TO 'Y' AXIS)
TORSIONAL CONSTANT		=	1.6008E-03	

SECTION COORDINATES

POINT NO	XS	YS	XP	YP
1	-9.58721E-01	-1.16683E+00	-9.50936E-01	-1.17249E+00
2	-9.22253E-01	-1.09798E+00	-9.07677E-01	-1.10864E+00
3	-8.85677E-01	-1.02963E+00	-8.64358E-01	-1.04533E+00
4	-8.48967E-01	-9.61882E-01	-8.20994E-01	-9.82670E-01
5	-8.12101E-01	-8.94835E-01	-7.77606E-01	-9.20760E-01
6	-7.75050E-01	-8.28587E-01	-7.34217E-01	-8.59682E-01
7	-7.37803E-01	-7.63230E-01	-6.90846E-01	-7.99520E-01
8	-7.00345E-01	-6.98853E-01	-6.47525E-01	-7.40355E-01
9	-6.62648E-01	-6.35543E-01	-6.04267E-01	-6.82263E-01
10	-6.24710E-01	-5.73378E-01	-5.61109E-01	-6.25319E-01
11	-5.86528E-01	-5.12435E-01	-5.18041E-01	-5.69596E-01
12	-5.48056E-01	-4.52788E-01	-4.75086E-01	-5.15163E-01
13	-5.09319E-01	-3.94510E-01	-4.32219E-01	-4.62081E-01
14	-4.70276E-01	-3.37671E-01	-3.89461E-01	-4.10410E-01
15	-4.30882E-01	-2.82336E-01	-3.46777E-01	-3.60207E-01
16	-3.91148E-01	-2.28571E-01	-3.04186E-01	-3.11522E-01
17	-3.51043E-01	-1.76434E-01	-2.61649E-01	-2.64400E-01
18	-3.10527E-01	-1.25983E-01	-2.19175E-01	-2.18881E-01
19	-2.69617E-01	-7.72726E-02	-1.76744E-01	-1.74998E-01
20	-2.28243E-01	-3.03519E-02	-1.34365E-01	-1.32782E-01
21	-1.86426E-01	1.47322E-02	-9.20552E-02	-9.22559E-02
22	-1.44149E-01	5.79363E-02	-4.97983E-02	-5.34430E-02
23	-1.01412E-01	9.92193E-02	-7.63321E-03	-1.63615E-02
24	-5.82406E-02	1.38542E-01	3.44781E-02	1.89728E-02
25	-1.46168E-02	1.75865E-01	7.64962E-02	5.25474E-02
26	2.94213E-02	2.11152E-01	1.18457E-01	8.43513E-02
27	7.38861E-02	2.44366E-01	1.60345E-01	1.14376E-01
28	1.18741E-01	2.75466E-01	2.02161E-01	1.42621E-01
29	1.63997E-01	3.04407E-01	2.43938E-01	1.69093E-01
30	2.09617E-01	3.31147E-01	2.85675E-01	1.93807E-01
31	2.55609E-01	3.55642E-01	3.27430E-01	2.16783E-01
32	3.01953E-01	3.77859E-01	3.69211E-01	2.38048E-01
33	3.48649E-01	3.97767E-01	4.11059E-01	2.57636E-01
34	3.95682E-01	4.15342E-01	4.53018E-01	2.75584E-01

POINT NO	XS	YS	XP	YP
35	4.43033E-01	4.30574E-01	4.95114E-01	2.91940E-01
36	4.90690E-01	4.4[illegible]4[illegible]E-01	5.37412E-01	3.06756E-01
37	5.38013E-01	4.54097E-01	5.79935E-01	3.20091E-01
38	5.86796E-01	4.62238E-01	6.22733E-01	3.32011E-01
39	6.35177E-01	4.68192E-01	6.65848E-01	3.42580E-01
40	6.83738E-01	4.71918E-01	7.09287E-01	3.51839E-01
41	7.32396E-01	4.73407E-01	7.53086E-01	3.59811E-01
42	7.81106E-01	4.72693E-01	7.97258E-01	3.66515E-01
43	8.29808E-01	4.69770E-01	8.41825E-01	3.71976E-01
44	8.78463E-01	4.64646E-01	8.86813E-01	3.76209E-01
45	9.27027E-01	4.57312E-01	9.32238E-01	3.79209E-01
46	9.75479E-01	4.47738E-01	9.78117E-01	3.80965E-01
47	1.02379E+00	4.35884E-01	1.02447E+00	3.81456E-01
48	1.07195E+00	4.21691E-01	1.07132E+00	3.80650E-01
49	1.11995E+00	4.05085E-01	1.11867E+00	3.78507E-01
50	1.16782E+00	3.86038E-01	1.16655E+00	3.75047E-01

POINT NO	XSEMI	YSEMI
1	-9.50936E-01	-1.17249E+00
2	-9.51227E-01	-1.17293E+00
3	-9.51557E-01	-1.17333E+00
4	-9.51923E-01	-1.17369E+00
5	-9.52321E-01	-1.17400E+00
6	-9.52746E-01	-1.17427E+00
7	-9.53195E-01	-1.17449E+00
8	-9.53661E-01	-1.17465E+00
9	-9.54139E-01	-1.17476E+00
10	-9.54626E-01	-1.17482E+00
11	-9.55114E-01	-1.17481E+00
12	-9.55600E-01	-1.17476E+00
13	-9.56077E-01	-1.17464E+00
14	-9.56540E-01	-1.17447E+00
15	-9.56985E-01	-1.17425E+00
16	-9.57406E-01	-1.17398E+00
17	-9.57799E-01	-1.17366E+00
18	-9.58159E-01	-1.17329E+00
19	-9.58483E-01	-1.17289E+00
20	-9.58767E-01	-1.17245E+00
21	-9.59007E-01	-1.17198E+00
22	-9.59202E-01	-1.17149E+00
23	-9.59349E-01	-1.17097E+00
24	-9.59447E-01	-1.17044E+00
25	-9.59493E-01	-1.16991E+00
26	-9.59499E-01	-1.16937E+00
27	-9.59433E-01	-1.16883E+00
28	-9.59327E-01	-1.16830E+00
29	-9.59172E-01	-1.16779E+00
30	-9.58969E-01	-1.16730E+00
31	-9.58721E-01	-1.16683E+00

3. EXPONENTIAL CAMBER LINE

a. Input Data

As mentioned previously, the overall design incorporated in the polynomial camber line example was also assumed for the exponential camber line example. The discussion of the input data therefore highlights the changes made to the polynomial camber line example data in order to create the exponential camber line example.

The exponential camber line is specified by setting ISECN equal to 1. For this example, chords rather than meridionally-projected chords are specified. The chord lengths used are taken from the results of the polynomial camber line example, and because of the different camber line configurations, the resulting meridionally-projected chords are somewhat smaller for the exponential camber line case. The parameters PP and QQ are set equal to 0.5 for all sections. These values will probably be satisfactory for most applications of the blade profile. The only remaining change to the polynomial camber line input data is to specify the distributions of the inflection point and change in camber angle from blade inlet to the inflection point. The distributions used for the example are quite arbitrary, but representative of what might be indicated by a typical aerodynamic analysis. The inflection point is located at the leading edge on the innermost streamsurface section, and moved rearward .05 per streamsurface, to .35 (of the meridionally-projected chord) at the casing. (As a value of s of zero is not acceptable, the value used for the innermost section is .01.) For the three innermost sections, the inflection angle is set equal to the inlet angle. Thus, these sections have straight leading edge portions (of length from zero to .1 of the meridionally-projected chord), followed by portions of continuously-positive camber. The remaining sections have inflection angles that are greater than the section inlet angles, the difference in angles rising from zero at the third section (as described above) to seven degrees at the casing. Thus, these sections have reverse and positive camber, the reverse camber increasing with radius, as the inflection point also moves rearward.

The input data deck is listed below.

FIGURE   EXAMPLE BLADE DESIGN - EXPONENTIAL CAMBER LINE

```
  8   8   6   8 50  30   2   0   1   1   3   0
6.5          9.0           5.0         0.0          12.0
  1  0
-1.4357      0.0
6.623
6.9746
7.3197
7.6645
8.0126
8.3681
8.7350
9.12
  2  0
-1.6357      0.0
-1.0264      6.75
6.75
7.0689
7.3844
7.6994
8.0159
8.3365
8.6629
9.0
  1  1
-.5767       0.0
6.8864
7.1634
7.4420
7.7259
8.0169
8.3160
8.6233
8.9382
  1  1
-.2087       0.0
6.9872
7.2338
7.4849
7.7421
8.0063
8.2777
8.5558
8.8417
  1  1
.20003       0.0
7.0786
7.2950
7.5164
7.7436
```

7.9770					
8.2201					
8.4732					
8.7345					
1 1					
.6093	0.0				
7.1496					
7.3387					
7.5325					
7.7325					
7.9403					
8.1583					
8.3885					
8.6315					
2 0					
2.0623	0.0				
1.0269	7.2076				
7.2076					
7.3759					
7.5496					
7.7301					
7.9189					
8.1197					
8.3377					
8.5846					
1 0					
1.4273	0.0				
7.2715					
7.4214					
7.5768					
7.7380					
7.9054					
8.0805					
8.2651					
8.4624					
1.0	57.	8.309	0.5	0.5	.00175
.04857	.00175	0.6	2.87384		
0.01	0.0				
2.0	58.954	12.614	0.5	0.5	.00171
.04536	.00171	0.6	2.93388		
0.05	0.0				
3.0	60.858	16.336	0.5	0.5	.00167
.04243	.00167	0.6	3.00163		
0.1	0.0				
4.0	62.686	19.965	0.5	0.5	.00163
.03970	.00163	0.6	3.07600		
0.15	0.4				
5.0	64.348	23.758	0.5	0.5	.00159
.03731	.00159	0.6	3.15316		
0.2	1.22				

6.0	65.623	28.327	0.5	0.5	.00155
.03503	.00155	0.6	3.22147		
0.25	2.60				
7.0	66.471	34.37	0.5	0.5	.00153
.03317	.00153	0.6	3.28428		
0.3	4.72				
8.0	67.1	42.52	0.5	0.5	.00150
.03129	.00150	0.6	3.38031		
0.35	7.0				

b. Output Data

The input calls for all optional printed output. As this is identical in format to that shown for the polynomial camber line example, none has been reproduced here.

Figures 21 and 22 show (at reduced size) the superimposed streamsurface section and manufacturing section plots. The comments regarding extrapolation made in connection with the polynomial camber line example again apply. A comparison of some intermediate sections from both plots shows well the value of an accurate method of determining manufacturing coordinate data from streamsurface design data. For blades where the streamsurface section form is critical throughout the section, any approximate method based upon blade edge geometry only is unlikely to be satisfactory.

4. DOUBLE-CIRCULAR-ARC BLADE

a. Input Data

This example illustrates several program features not illustrated by the previous examples. First, this example illustrates curvilinear computing stations. Secondly, the blade is described in terms of negative inlet angle, illustrating that the program accommodates blades specified in either sense. This allows stators to be specified in the opposite sense to rotors, if desired. Finally, the blade is stacked at its trailing edge, rather than at, or offset slightly from, the centroid.

The double-circular-arc blade is specified by setting ISECN equal to 2. The particular example illustrates a novel design concept in that the leading edge is swept from hub and tip toward mid-passage, a concept which is described in further detail in Reference 4.

The input data is listed below.

```
        FIGURE      EXAMPLE CASE - DOUBLE CIRCULAR ARC BLADE
  8   5   5   8 50 49  1  0  2  1  3  2
7.5          8.625        5.0        5.         12.0
  8  1
  2.787900  7.627200
  2.974800  7.747200
  3.115200  7.872800
  3.201200  8.004500
  3.224100  8.142000
  3.174600  8.286200
  3.040600  8.439200
  2.790400  8.611400
  7.627200
  7.747200
  7.872800
  8.004500
  8.142000
  8.286200
  8.439200
  8.611400
  8  1
  3.340925  7.732600
  3.481100  7.833480
  3.586400  7.940981
  3.650900  8.054948
  3.668075  8.174438
  3.630950  8.298995
  3.530450  8.428176
  3.342800  8.563800
  7.732600
  7.833480
  7.940981
  8.054948
  8.174438
  8.298995
  8.428176
  8.563800
  8  1
  3.893950  7.746700
  3.987400  7.847329
  4.057600  7.955332
  4.100600  8.069974
  4.112050  8.189528
  4.087300  8.313028
  4.020300  8.439458
  3.895200  8.569200
  7.746700
  7.847329
  7.955332
  8.069974
```

8.189528
8.313028
8.439458
8.569200
8 1

4.446975	7.707700
4.493700	7.821264
4.528800	7.940688
4.550300	8.064728
4.556025	8.191289
4.543650	8.319699
4.511150	8.449053
4.447600	8.579700

7.707700
7.821264
7.940688
8.064728
8.191289
8.319699
8.449053
8.579700
1 1
5.
7.681900
7.805342
7.932725
8.063070
8.194276
8.325999
8.457433
8.589100

1.0000	-45.8950	8.4950		.0021
.0400	.0021	.5000	2.3490	
2.0000	-45.7650	9.0050		.0023
.0400	.0023	.5000	2.1430	
3.0000	-45.8250	9.5050		.0025
.0400	.0025	.5000	1.9900	
4.0000	-45.9550	9.8950		.0026
.0400	.0026	.5000	1.8950	
5.0000	-46.2450	10.1450		.0027
.0400	.0027	.5000	1.8690	
6.0000	-46.7750	10.2150		.0026
.0400	.0026	.5000	1.9230	
7.0000	-48.1350	10.2150		.0024
.0400	.0024	.5000	2.0720	
8.0000	-51.9050	10.4450		.0021
.0400	.0021	.5000	2.3650	

b. Output Data

The printed output for this example is similar in most respects to that shown for the polynomial camber line. The section entitled "Dimensional Results" is shown for streamsurface section 1 to illustrate that the section coordinates are presented relative to the stack axis which, in this case, has been specified at the blade trailing edge. Two other minor differences in comparison to the polynomial camber line output are related to the trailing edge: The printout contains the coordinate location of the center of the trailing edge as well as the 31 points distributed around the trailing edge. The latter feature also appears with the printout of the manufacturing sections (not reproduced here).

Figures 23 and 24 show (at reduced size) streamsurface section and manufacturing section plots, respectively. The comments regarding extrapolation made in connection with the polynomial camber line example again apply.

DIMENSIONAL RESULTS - ALL RESULTS REFER TO A BLADE OF SPECIFIED CHORD
****

BLADE CHORD = 2.34900E+00

END RADII = 4.93290E-03 CENTERED AT X= -2.22058E+00 Y= 7.49957E-01
AND X= -4.93290E-03 Y= 0.

SECTION AREA = 1.59493E-01

SECOND MOMENTS OF AREA ABOUT CENTROID

IX = 5.62156E-03
IY = 4.47580E-02
IXY =-1.48966E-02

PRINCIPAL SECOND MOMENTS OF AREA ABOUT CENTROID

IPX = 7.80367E-04 (AT-18.705 WITH 'X' AXIS)
IPY = 4.97991E-02 (AT-18.705 WITH 'Y' AXIS)

PT NO	SUCTION------SURFACE X	Y	PRESSURE-----SURFACE X	Y	PT NO	SUCTION------SURFACE X	Y	PRESSURE-----SURFACE X	Y
1	-2.21703E+00	7.53396E-01	-2.22414E+00	7.46516E-01	2	-2.16895E+00	7.11002E-01	-2.18179E+00	6.97916E-01
3	-2.12121E+00	6.70724E-01	-2.13909E+00	6.51598E-01	4	-2.07381E+00	6.32403E-01	-2.09606E+00	6.07422E-01
5	-2.02670E+00	5.95902E-01	-2.05273E+00	5.65265E-01	6	-1.97988E+00	5.61099E-01	-2.00912E+00	5.25022E-01
7	-1.93330E+00	5.27866E-01	-1.96526E+00	4.86597E-01	8	-1.88696E+00	4.96176E-01	-1.92116E+00	4.49906E-01
9	-1.84084E+00	4.65877E-01	-1.87659E+00	4.14875E-01	10	-1.79492E+00	4.36917E-01	-1.83233E+00	3.81437E-01
11	-1.74919E+00	4.09230E-01	-1.78763E+00	3.49531E-01	12	-1.70363E+00	3.82755E-01	-1.74276E+00	3.19103E-01
13	-1.65822E+00	3.57437E-01	-1.69773E+00	2.90102E-01	14	-1.61296E+00	3.33227E-01	-1.65255E+00	2.62484E-01
15	-1.56784E+00	3.10082E-01	-1.60725E+00	2.36208E-01	16	-1.52283E+00	2.87959E-01	-1.56182E+00	2.11235E-01
17	-1.47793E+00	2.66623E-01	-1.51628E+00	1.87531E-01	18	-1.43314E+00	2.46640E-01	-1.47064E+00	1.65066E-01
19	-1.38843E+00	2.27360E-01	-1.42491E+00	1.43608E-01	20	-1.34381E+00	2.09014E-01	-1.37910E+00	1.23732E-01
21	-1.29926E+00	1.91517E-01	-1.33322E+00	1.04812E-01	22	-1.25477E+00	1.74866E-01	-1.28727E+00	8.70263E-02
23	-1.21034E+00	1.59040E-01	-1.24127E+00	7.03528E-02	24	-1.16595E+00	1.44020E-01	-1.19522E+00	5.47722E-02
25	-1.12160E+00	1.29787E-01	-1.14914E+00	4.02663E-02	26	-1.07728E+00	1.16328E-01	-1.10302E+00	2.68183E-02
27	-1.03299E+00	1.03626E-01	-1.05688E+00	1.44127E-02	28	-9.88711E-01	9.16688E-02	-1.01072E+00	3.03513E-03
29	-9.44443E-01	8.04450E-02	-9.64553E-01	-7.32764E-03	30	-9.00178E-01	6.99443E-02	-9.18384E-01	-1.66878E-02
31	-8.55908E-01	6.01575E-02	-8.72216E-01	-2.50568E-02	32	-8.11628E-01	5.10763E-02	-8.26064E-01	-3.24447E-02
33	-7.67330E-01	4.26939E-02	-7.79927E-01	-3.88612E-02	34	-7.23008E-01	3.50043E-02	-7.33814E-01	-4.43148E-02
35	-6.78657E-01	2.80024E-02	-6.87731E-01	-4.88135E-02	36	-6.34269E-01	2.16843E-02	-6.41684E-01	-5.23644E-02
37	-5.89838E-01	1.60466E-02	-5.95660E-01	-5.49737E-02	38	-5.45359E-01	1.10878E-02	-5.49724E-01	-5.66473E-02
39	-5.00826E-01	6.60589E-03	-5.03823E-01	-5.73899E-02	40	-4.56231E-01	3.20074E-03	-4.57982E-01	-5.72061E-02
41	-4.11571E-01	2.72742E-04	-4.12208E-01	-5.60993E-02	42	-3.66838E-01	-1.97682E-03	-3.66500E-01	-5.40727E-02
43	-3.22027E-01	-3.54581E-03	-3.20883E-01	-5.11284E-02	44	-2.77131E-01	-4.43123E-03	-2.75343E-01	-4.72684E-02
45	-2.32146E-01	-4.82920E-03	-2.29894E-01	-4.24936E-02	46	-1.87065E-01	-4.13500E-03	-1.84540E-01	-3.68044E-02
47	-1.41882E-01	-2.94299E-03	-1.39288E-01	-3.02007E-02	48	-9.65911E-02	-1.04665E-03	-9.41442E-02	-2.26815E-02
49	-5.11870E-02	1.56146E-03	-4.91136E-02	-1.42453E-02	50	-5.66326E-03	4.88984E-03	-4.20254E-03	-4.88984E-03

POINTS DESCRIBING LEADING AND TRAILING EDGES

POINT NO.	LEADING EDGE X	LEADING EDGE Y	TRAILING EDGE X	TRAILING EDGE Y
1	-2.22414E+00	7.46516E-01	-5.66326E-03	4.88984E-03
2	-2.22435E+00	7.46774E-01	-5.33162E-03	4.91676E-03
3	-2.22467E+00	7.47196E-01	-4.80253E-03	4.93118E-03
4	-2.22495E+00	7.47650E-01	-4.27493E-03	4.88882E-03
5	-2.22517E+00	7.48130E-01	-3.75492E-03	4.79018E-03
6	-2.22534E+00	7.48632E-01	-3.24846E-03	4.63640E-03
7	-2.22545E+00	7.49149E-01	-2.76140E-03	4.42923E-03
8	-2.22551E+00	7.49675E-01	-2.29934E-03	4.17107E-03
9	-2.22551E+00	7.50204E-01	-1.86760E-03	3.86490E-03
10	-2.22546E+00	7.50730E-01	-1.47114E-03	3.51422E-03
11	-2.22535E+00	7.51246E-01	-1.11455E-03	3.12309E-03
12	-2.22518E+00	7.51751E-01	-8.01909E-04	2.69600E-03
13	-2.22496E+00	7.52233E-01	-5.36830E-04	2.23787E-03
14	-2.22469E+00	7.52688E-01	-3.22363E-04	1.75398E-03
15	-2.22438E+00	7.53113E-01	-1.60976E-04	1.24990E-03
16	-2.22402E+00	7.53501E-01	-5.45270E-05	7.31423E-04
17	-2.22362E+00	7.53846E-01	-4.24189E-06	2.04528E-04
18	-2.22318E+00	7.54151E-01	-1.06995E-05	-3.24722E-04
19	-2.22272E+00	7.54405E-01	-7.38254E-05	-8.50233E-04
20	-2.22223E+00	7.54606E-01	-1.92893E-04	-1.36596E-03
21	-2.22172E+00	7.54757E-01	-3.66531E-04	-1.86595E-03
22	-2.22120E+00	7.54851E-01	-5.92741E-04	-2.34447E-03
23	-2.22067E+00	7.54889E-01	-8.68919E-04	-2.79599E-03
24	-2.22014E+00	7.54870E-01	-1.19188E-03	-3.21532E-03
25	-2.21962E+00	7.54794E-01	-1.55792E-03	-3.59764E-03
26	-2.21911E+00	7.54663E-01	-1.96281E-03	-3.93854E-03
27	-2.21861E+00	7.54478E-01	-2.40189E-03	-4.23409E-03
28	-2.21814E+00	7.54240E-01	-2.87012E-03	-4.48090E-03
29	-2.21769E+00	7.53953E-01	-3.36209E-03	-4.67612E-03
30	-2.21728E+00	7.53621E-01	-3.87215E-03	-4.81750E-03
31	-2.21703E+00	7.53396E-01	-4.20254E-03	-4.88984E-03

CARTESIAN COORDINATES ON STREAMSURFACE 1

POINT NO	ZS	XS	YS	ZP	XP	YP
1	7.59269E+00	-2.20398E+00	7.43905E-01	7.59180E+00	-2.21083E+00	7.36943E-01
2	7.60722E+00	-2.15754E+00	7.02605E-01	7.60560E+00	-2.16996E+00	6.89316E-01
3	7.62120E+00	-2.11126E+00	6.63396E-01	7.61895E+00	-2.12862E+00	6.44008E-01
4	7.63462E+00	-2.06517E+00	6.26044E-01	7.63186E+00	-2.08683E+00	6.00761E-01
5	7.64746E+00	-2.01921E+00	5.90416E-01	7.64429E+00	-2.04462E+00	5.59456E-01
6	7.65969E+00	-1.97336E+00	5.56395E-01	7.65624E+00	-2.00201E+00	5.19988E-01
7	7.67127E+00	-1.92767E+00	5.23879E-01	7.66767E+00	-1.95905E+00	4.82264E-01
8	7.68216E+00	-1.88207E+00	4.92779E-01	7.67853E+00	-1.91573E+00	4.46202E-01
9	7.69232E+00	-1.83658E+00	4.63013E-01	7.68880E+00	-1.87210E+00	4.11730E-01
10	7.70172E+00	-1.79118E+00	4.34513E-01	7.69841E+00	-1.82817E+00	3.78781E-01
11	7.71029E+00	-1.74587E+00	4.07215E-01	7.70731E+00	-1.78396E+00	3.47299E-01
12	7.71801E+00	-1.70065E+00	3.81064E-01	7.71546E+00	-1.73949E+00	3.17232E-01
13	7.72481E+00	-1.65552E+00	3.56010E-01	7.72279E+00	-1.69479E+00	2.88533E-01
14	7.73068E+00	-1.61046E+00	3.32010E-01	7.72925E+00	-1.64988E+00	2.61159E-01
15	7.73565E+00	-1.56548E+00	3.09026E-01	7.73479E+00	-1.60476E+00	2.35076E-01
16	7.73977E+00	-1.52057E+00	2.87026E-01	7.73945E+00	-1.55948E+00	2.10252E-01
17	7.74309E+00	-1.47574E+00	2.65979E-01	7.74326E+00	-1.51403E+00	1.86659E-01

POINT NO	ZS	XS	YS	ZF	XF	YF
18	7.74566E+00	-1.43099E+00	2.45859E-01	7.74627E+00	-1.46846E+00	1.64272E-01
19	7.74751E+00	-1.38630E+00	2.26638E-01	7.74852E+00	-1.42276E+00	1.43067E-01
20	7.74871E+00	-1.34169E+00	2.08295E-01	7.75004E+00	-1.37697E+00	1.23022E-01
21	7.74928E+00	-1.29714E+00	1.90607E-01	7.75089E+00	-1.33109E+00	1.04117E-01
22	7.74928E+00	-1.25265E+00	1.74154E-01	7.75110E+00	-1.28515E+00	8.63327E-02
23	7.74875E+00	-1.20822E+00	1.58319E-01	7.75071E+00	-1.23915E+00	6.96516E-02
24	7.74771E+00	-1.16385E+00	1.43285E-01	7.74977E+00	-1.19311E+00	5.40569E-02
25	7.74623E+00	-1.11952E+00	1.29037E-01	7.74833E+00	-1.14704E+00	3.95330E-02
26	7.74433E+00	-1.07525E+00	1.15558E-01	7.74642E+00	-1.10096E+00	2.60648E-02
27	7.74206E+00	-1.03101E+00	1.02836E-01	7.74409E+00	-1.05487E+00	1.36373E-02
28	7.73946E+00	-9.86810E-01	9.08618E-02	7.74141E+00	-1.00878E+00	2.23932E-03
29	7.73663E+00	-9.42635E-01	7.96230E-02	7.73842E+00	-9.62701E-01	-8.14143E-03
30	7.73357E+00	-8.98478E-01	6.91101E-02	7.73518E+00	-9.16637E-01	-1.75164E-02
31	7.73034E+00	-8.54329E-01	5.93142E-02	7.73176E+00	-8.70593E-01	-2.58964E-02
32	7.72699E+00	-8.10180E-01	5.02274E-02	7.72820E+00	-8.24572E-01	-3.32917E-02
33	7.72357E+00	-7.66020E-01	4.18426E-02	7.72457E+00	-7.78577E-01	-3.97117E-02
34	7.72014E+00	-7.21840E-01	3.41536E-02	7.72093E+00	-7.32611E-01	-4.51856E-02
35	7.71673E+00	-6.77629E-01	2.71550E-02	7.71731E+00	-6.86675E-01	-4.96614E-02
36	7.71339E+00	-6.33379E-01	2.08423E-02	7.71379E+00	-6.40772E-01	-5.32069E-02
37	7.71018E+00	-5.89078E-01	1.52118E-02	7.71041E+00	-5.94903E-01	-5.58092E-02
38	7.70714E+00	-5.44718E-01	1.02609E-02	7.70722E+00	-5.49072E-01	-5.74744E-02
39	7.70430E+00	-5.00292E-01	5.98759E-03	7.70427E+00	-5.03282E-01	-5.82083E-02
40	7.70166E+00	-4.55793E-01	2.39103E-03	7.70154E+00	-4.57540E-01	-5.80156E-02
41	7.69919E+00	-4.11216E-01	-5.28525E-04	7.69901E+00	-4.11851E-01	-5.69002E-02
42	7.69688E+00	-3.66555E-01	-2.77006E-03	7.69667E+00	-3.66224E-01	-5.48654E-02
43	7.69472E+00	-3.21807E-01	-4.33160E-03	7.69449E+00	-3.20664E-01	-5.19137E-02
44	7.69268E+00	-2.76965E-01	-5.21030E-03	7.69245E+00	-2.75179E-01	-4.80469E-02
45	7.69075E+00	-2.32024E-01	-5.40237E-03	7.69054E+00	-2.29774E-01	-4.32662E-02
46	7.68892E+00	-1.86980E-01	-4.90319E-03	7.68872E+00	-1.84457E-01	-3.75722E-02
47	7.68715E+00	-1.41827E-01	-3.70718E-03	7.68699E+00	-1.39235E-01	-3.09646E-02
48	7.68544E+00	-9.65593E-02	-1.60790E-03	7.68531E+00	-9.41135E-02	-2.34426E-02
49	7.68376E+00	-5.11726E-02	8.02022E-04	7.68367E+00	-4.91001E-02	-1.50047E-02
50	7.68210E+00	-5.66188E-03	4.16418E-03	7.68205E+00	-4.20152E-03	-5.61263E-03

POINT NO	ZSEMI	XSEMI	YSEMI	ZSEMJ	XSEMJ	YSEMJ
1	7.59180E+00	-2.21083E+00	7.36943E-01	7.68210E+00	-5.66188E-03	4.16418E-03
2	7.59173E+00	-2.21104E+00	7.37196E-01	7.68209E+00	-5.33032E-03	4.19175E-03
3	7.59162E+00	-2.21135E+00	7.37611E-01	7.68207E+00	-4.80136E-03	4.20721E-03
4	7.59152E+00	-2.21161E+00	7.38058E-01	7.68205E+00	-4.27389E-03	4.16589E-03
5	7.59142E+00	-2.21183E+00	7.38533E-01	7.68204E+00	-3.75400E-03	4.06828E-03
6	7.59134E+00	-2.21199E+00	7.39029E-01	7.68202E+00	-3.24767E-03	3.91549E-03
7	7.59126E+00	-2.21210E+00	7.39542E-01	7.68200E+00	-2.76073E-03	3.70928E-03
8	7.59120E+00	-2.21216E+00	7.40064E-01	7.68198E+00	-2.29878E-03	3.45203E-03
9	7.59115E+00	-2.21218E+00	7.40591E-01	7.68197E+00	-1.86714E-03	3.14671E-03
10	7.59111E+00	-2.21211E+00	7.41116E-01	7.68195E+00	-1.47079E-03	2.79681E-03
11	7.59108E+00	-2.21200E+00	7.41633E-01	7.68194E+00	-1.11428E-03	2.40638E-03
12	7.59107E+00	-2.21184E+00	7.42136E-01	7.68193E+00	-8.01714E-04	1.97990E-03
13	7.59107E+00	-2.21163E+00	7.42619E-01	7.68192E+00	-5.36700E-04	1.52230E-03
14	7.59108E+00	-2.21137E+00	7.43077E-01	7.68191E+00	-3.22285E-04	1.03883E-03
15	7.59111E+00	-2.21106E+00	7.43505E-01	7.68191E+00	-1.60937E-04	5.35061E-04
16	7.59115E+00	-2.21072E+00	7.43897E-01	7.68190E+00	-5.45137E-05	1.67957E-05
17	7.59121E+00	-2.21033E+00	7.44249E-01	7.68190E+00	-4.24085E-06	-5.10001E-04
18	7.59127E+00	-2.20991E+00	7.44556E-01	7.68190E+00	-1.06969E-05	-1.03926E-03
19	7.59135E+00	-2.20946E+00	7.44817E-01	7.68190E+00	-7.38074E-05	-1.56490E-03
20	7.59144E+00	-2.20899E+00	7.45027E-01	7.68191E+00	-1.92846E-04	-2.08085E-03
21	7.59153E+00	-2.20850E+00	7.45183E-01	7.68191E+00	-3.66442E-04	-2.58119E-03
22	7.59164E+00	-2.20800E+00	7.45285E-01	7.68192E+00	-5.92597E-04	-3.06015E-03

POINT NO	ZSEMI	XSEMI	YSEMI	ZSEMJ	XSEMJ	YSEMJ
23	7.59175E+00	-2.20749E+00	7.45331E-01	7.68193E+00	-8.68707E-04	-3.51222E-03
24	7.59187E+00	-2.20698E+00	7.45321E-01	7.68194E+00	-1.19159E-03	-3.93218E-03
25	7.59199E+00	-2.20648E+00	7.45254E-01	7.68196E+00	-1.55754E-03	-4.31522E-03
26	7.59211E+00	-2.20598E+00	7.45131E-01	7.68197E+00	-1.96233E-03	-4.65691E-03
27	7.59224E+00	-2.20550E+00	7.44955E-01	7.68199E+00	-2.40131E-03	-4.95333E-03
28	7.59237E+00	-2.20505E+00	7.44728E-01	7.68200E+00	-2.86942E-03	-5.20106E-03
29	7.59249E+00	-2.20462E+00	7.44447E-01	7.68202E+00	-3.36127E-03	-5.39725E-03
30	7.59262E+00	-2.20422E+00	7.44123E-01	7.68204E+00	-3.87120E-03	-5.53963E-03
31	7.59269E+00	-2.20398E+00	7.43905E-01	7.68205E+00	-4.20152E-03	-5.61263E-03

5. MULTIPLE-CIRCULAR-ARC CAMBER LINE

a. Input Data

The same overall design incorporated in the first two examples was also assumed for the multiple-circular-arc camber line example. The discussion of the input data will be limited to changes made to the exponential camber line example to create the multiple-circular-arc camber line example.

The multiple-circular-arc camber line is specified by setting ISECN equal to 3. The only other changes made to the exponential camber line example are the distributions of inflection point and the change in camber angle from blade inlet to the inflection point. The inflection point has been arbitrarily set at 0.3 (of the meridionally-projected chord) on all streamsurfaces. The change in camber angle has been specified in such a way that the blade has positive camber in the leading segment at the hub, gradually decreasing to zero camber (straight line leading segment) on streamsurface 4, and producing sections with reverse camber on the four outermost streamsurfaces.

The input data deck is listed below.

```
     FIGURE   MULTIPLE CIRCULAR ARC CAMBER LINE
  8   8   6   8 50 30   2   0   3   1   3   0
6.5          9.0          5.0          0.0          12.0
  1  0
-1.4357      0.0
6.623
6.9746
7.3197
7.6645
8.0126
8.3681
8.7350
9.12
  2  0
-1.6357      0.0
-1.0264      6.75
6.75
7.0689
7.3844
7.6994
8.0159
8.3365
8.6629
9.0
  1  1
-.5767       0.0
6.8864
7.1634
7.4420
7.7259
8.0169
8.3160
8.6233
8.9382
  1  1
-.2087       0.0
6.9872
7.2338
7.4849
7.7421
```

8.0063	
8.2777	
8.5558	
8.8417	
1 1	
.20003	0.0
7.0786	
7.2950	
7.5164	
7.7436	
7.9770	
8.2201	
8.4732	
8.7345	
1 1	
.6093	0.0
7.1496	
7.3387	
7.5325	
7.7325	
7.9403	
8.1583	
8.3885	
8.6319	
2 0	
2.0623	0.0
1.0269	7.2076
7.2076	
7.3759	
7.5496	
7.7301	
7.9189	
8.1197	
8.3377	
8.5846	
1 0	
1.4273	0.0
7.2715	
7.4214	
7.5768	

7.7380					
7.9054					
8.0805					
8.2651					
8.4624					
1.0	-57.	-8.809	0.0	0.5	.00175
.04857	.00175	0.6	2.1109		
0.3	5.471				
2.0	-58.954	-12.614	0.0	0.5	.00171
.04538	.00171	0.6	2.0525		
0.3	3.619				
3.0	-60.858	-16.336	0.0	0.5	.00167
.04243	.00167	0.6	1.9940		
0.3	1.80				
4.0	-62.686	-19.965	0.0	0.5	.00163
.03970	.00163	0.6	1.9356		
0.3	0.0				
5.0	-64.348	-23.758	0.0	0.5	.00159
.03731	.00159	0.6	1.8771		
0.3	-2.131				
6.0	-65.623	-28.327	0.0	0.5	.00155
.03503	.00155	0.6	1.8187		
0.3	-5.425				
7.0	-66.471	-34.37	0.0	0.5	.00153
.03317	.00153	0.6	1.7603		
0.3	-10.62				
8.0	-67.1	-42.52	0.0	0.5	.00150
.03129	.00150	0.6	1.7018		
0.3	-18.141				

b. Output Data

The input data calls for all optional printed output. As this is identical in format to that shown for the polynomial camber line, none has been reproduced here.

Figures 25 and 26 show (at reduced size) the superimposed streamsurface section and manufacturing section plots, respectively. The comments regarding extrapolation made in connection with the polynomial camber line example are again applicable.

SECTION IX

COMPUTER PROGRAM DETAILS

1. IMPLEMENTATION OF THE COMPUTER PROGRAM

The program is written in FORTRAN IV and was developed on an IBM 7094/7044 Direct Couple System (incorporating the version 13 IBSYS Operating System) and a CDC 6000 Series System (incorporating the version 3.3 SCOPE Operating System). When loaded into core, the program (and resident system) occupies about 32K of storage, so that the program will probably not be usable without modification on a relatively small computer. Apart from this limitation, the program should be compatible with the majority of modern computing systems. The program consists of a main program, and Subroutines BQ, CQ, D1, EQ, FQ and GQ. The seven decks have been given the identifiers A, B, C, D, E, F and G, respectively. Listings of the decks are shown below, and the deck set-up required for the CDC 6000 Series System is also presented.

The program uses three numerical system units for its input and output routines. Input is drawn from the card unit via READ statements referring to Unit LOG 1; output is sent to the line printer by WRITE statements referring to Unit LOG 2; and punched output is produced via WRITE statements referenced to Unit LOG 3. Units LOG 1, LOG 2, and LOG 3 are set equal to 5, 6, and 7, respectively on cards A1140-60 in the FORTRAN programming. On the CDC 6000 Series System, the "PROGRAM" card must also establish the input and output linkages. On other computing systems, the "PROGRAM" card may not be required, and the input-output files may be established via control cards.

The program as presented herein utilizes an on-line precision plotting capability available at the program development site. Calls to four subroutines not included in the deck are included in the program. These calls are executed only if precision plots are specified in the input data, and the entry points expressed are part of standard CALCOMP software normally supplied to users of CALCOMP precision plotting equipment. The various call statements used in the program are explained below, to facilitate modification should the need arise.

CALL PLOT (XPLOT, YPLOT, N)

The majority of plotting is done using this form of call. The parameters XPLOT and YPLOT are the "x" and "y" coordinates (in inches) on the paper to which the pen is being directed. The parameter N indicates pen up or down, $|N| = 3$ or $|N| = 2$ respectively, and will cause XPLOT or YPLOT to be assigned

as the origin for further coordinates if N is negative.

CALL SYMBOL (X, Y, H, TEXT, THETA, N)

This call is used to title the plots. The parameters X and Y are the coordinates (in inches) of the lower left hand corner of the first character, H is the character height (in inches), TEXT is the character to be printed, THETA is the angle of the lettering with respect to the "x" axis and N is the total number of characters to be printed.

CALL NUMBER (X, Y, H, F, THETA, N)

This call causes the printing of the number F. The parameters X, Y, H, and THETA are used as for CALL SYMBOL. The parameter N indicates the number of digits following the decimal point if positive, or truncation to an integer if equal to -1.

CALL PLOTE

This call terminates the tape.

In the event the program is used on a computing system which does not include CALCOMP software, and the operating system will not execute a program with unsatisfied external references, dummy entry points may be supplied by adding to the deck a subroutine such as the following:

```
SUBROUTINE PLOT

A = A

ENTRY SYMBOL

ENTRY NUMBER

ENTRY PLOTE

RETURN

END
```

2. DECK SETUP FOR CDC 6000 SERIES SYSTEM

The deck setup required to run the program on a CDC 6000 Series System incorporating the SCOPE 3.3 Operating System is shown below. Production runs of the program would usually employ relocatable binary forms of the routines produced from the source decks to avoid having to compile the FORTRAN for each run and the waste of associated computer resources.

```
JOB                 Identification, etc.
FTN.
LGO.
7/8/9  End of Record
  SOURCE DECK A
  SOURCE DECK B
  SOURCE DECK C
  SOURCE DECK D
  SOURCE DECK E
  SOURCE DECK F
  SOURCE DECK G
7/8/9  End of Record
  DATA DECK
6/7/8/9  End of Job
```

3. FORTRAN PROGRAM LISTING

A listing of the FORTRAN program appears on the following pages with each subroutine started on a new page.

```
      PROGRAM BLADE(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=
     1 PUNCH,PLOT)
C USAF - ARL(ARF)  HIGH MACH NUMBER COMPRESSOR BLADE PROGRAM
      COMMON EPZ( 80,4), R(10,15), ZOUT(15), SS(100), X(100), YPRIME(100
     1 ), YS(15, 80), YP(15, 80), XP(15, 80), XS(15, 80), YSEMI(15,31),
     2 XSEMI(15,31), ZS(15,80), ZP(15, 80), ZSEMI(15,31), TITLE( 8),
     3 XHERE(10), XTEMP(100), RAD(100), TEMP1(15), TEMP2(15), TEMP3(15),
     4 TEMP4(15), ZR(15), B1(15), B2(15), PP(15), QQ(15), ZZ(15),
     5 RLE(15), TC(15), TE(15), CORD(15), DELX(15), DELY(15), S(15),
     6 BS(15), XSEMJ(15,31), YSEMJ(15,31), ZSEMJ(15,31), XSTA(15,10),
     7 RSTA(15,10), KPTS(15), SIGMA(100), TANPHI(10,15), ZCAMB(15,10),
     8 YCAMB(15,10 ), IFANGS(10),     THETA(15,10 ), ALPHA(15,10 )
      REAL IX,IY,IXY,IPX,IPY,IXN,IYN,IXYN,IXD,IYD
      LOG1=5
      LOG2=6
      LOG3=7
      PI=3.1415926536
      C1=180.0/PI
      READ (LOG1,10) TITLE
   10 FORMAT(7A10,A2)
      WRITE(LOG2,11) TITLE
   11 FORMAT(1H1,36X,58HUSAF - ARL(ARF)  HIGH MACH NUMBER COMPRESSOR BLA
     1DE PROGRAM,/,37X,58(1H*),//,10X,5HTITLE,25X,1H=,7A10,A2)
      READ (LOG1,12) NLINES,NSTNS,NZ,NSPEC,NPOINT,NBLADE,ISTAK,IPUNCH,
     1 ISECN,IFCORD,IFPLOT,IPRINT
   12 FORMAT(12I3)
      WRITE(LOG2,13) NLINES,NSTNS,NZ,NSPEC,NPOINT,NBLADE,ISTAK,IPUNCH,
     1 ISECN,IFCORD,IFPLOT,IPRINT
   13 FORMAT(                                     10X,24HNUMBER OF STREA
     3MSURFACES,6X,1H=,I3,/,10X,18HNUMBER OF STATIONS,12X,1H=,I3,/,10X,2
     47HNUMBER OF CONSTANT-Z PLANES,3X,1H=,I3,/,10X,27HNUMBER OF BLADE D
     5ATA POINTS,3X,1H=,I3,/,10X,31HNUMBER OF POINTS ON SURFACES  =,I3,/
     A,10X,29HNUMBER OF BLADES IN BLADE ROW,1X,1H=,I3,/,10X,5HISTAK,25X,
     B 1H=,I3,/,10X,6HIPUNCH,24X,1H=,I3,/,10X,5HISECN,25X,1H=,I3,/
     7,10X,6HIFCORD,24X,1H=,I3,/,10X,6HIFPLOT,24X,1H=,I3,/,10X,5HIPRINT,
     824X,1H=,I3)
      READ (LOG1,14) ZINNER,ZOUTER,SCALE,STACKX,PLTSZE
   14 FORMAT(5F12.0)
      WRITE(LOG2,15) ZINNER,ZOUTER,SCALE,STACKX,PLTSZE
   15 FORMAT(     /,10X,6HZINNER,24X,1H=,F8.4,/,10X,6HZOUTER,24X,1H=,F8.
```

```
 94,/,1.X,5HSCALE,25X,1H=,F8.4,/,10X,6HSTACKX,24X,1H=,F8.4,/,10X,
 2 6HPLTSZE,24X,1H=,F8.4,//,20X,36HSTREAMSURFACE GEOMETRY SPECIFICAT
 3ION)
      IF(IFPLOT.EQ.0) GO TO 16
      Z=-PLTSZE
      CALL PLOT(0.0,Z,-3)
      CALL PLOT(0.0,0.5,-3)
   16 LNCT=23
      DO 60 I=1,NSTNS
      READ (LOG1,32) KPTS(I),IFANGS(I)
      KPT=KPTS(I)
      READ (LOG1,34) (XSTA(K,I), RSTA(K,I), K=1,KPT)
      IF(KPTS(I).GE.2) GO TO 25
      KPTS(I)=2
      XSTA(2,I)=XSTA(1,I)
      RSTA(2,I)=RSTA(1,I)+1.0
   25 READ (LOG1,36) (R(I,J), J=1,NLINES)
   32 FORMAT(2I3)
   34 FORMAT(2F12.0)
   36 FORMAT(F12.0)
      IDUM=KPTS(I)
      IF(NLINES.GT.IDUM) IDUM=NLINES
      IF(LNCT.LE.54-NLINES)GO TO 50
      WRITE(LOG2,40)
   40 FORMAT(1H1)
      LNCT=1
   50 LNCT=LNCT+IDUM+6
      WRITE(LOG2,51) I,KPTS(I),I,IFANGS(I)
   51 FORMAT(2X,/,10X,17HCOMPUTING STATION,I3,5X,28HNUMBER OF DESCRIBING
     A POINTS=,I3,6X,7HIFANGS(,I2,2H)=,I3,
     1           // 6X,11HDESCRIPTION,9X,10HSTREAMLINE,5X,5HRADII,/,
     2 6X,1HX,9X,1HR,11X,6HNUMBER,//,2X)
      DO 53 K=1,IDUM
      IF(K.LE.KPTS(I).AND.K.LE.NLINES) WRITE(LOG2,56) XSTA(K,I),RSTA(K,I
     1 ),K,R(I,K)
      IF(K.LE.KPTS(I).AND.K.GT.NLINES) WRITE(LOG2,57) XSTA(K,I),RSTA(K,I
     1 )
      IF(K.GT.KPTS(I).AND.K.LE.NLINES) WRITE(LOG2,58) K,R(I,K)
   53 CONTINUE
   56 FORMAT(3X,F8.4,2X,F8.4,8X,I2,9X,F8.4)
```

```
 57 FORMAT(3X,F8.4,2X,F8.4)
 58 FORMAT(29X,12,9X,F8.4)
 60 CONTINUE
    IF(ISECN.EQ.1.OR.ISECN.EQ.3)  GO TO 110
    IF(LNCT.LE.54-NSPEC)GO TO 80
    WRITE(LOG2,40)
    LNCT=1
 80 LNCT=LNCT+NSPEC+6
    READ(LOG1,90)  (ZR(J),B1(J),B2(J),PP(J),QQ(J),RLE(J),TC(J),TE(J),ZZ
   1(J),CORD(J),DELX(J),DELY(J),J=1,NSPEC)
 90 FORMAT(6F12.0)
    WRITE(LOG2,100)(ZR(J),B1(J),B2(J),PP(J),QQ(J),RLE(J),TC(J),TE(J),Z
   1Z(J),CORD(J),DELX(J),DELY(J),J=1,NSPEC)
100 FORMAT(2X,/,20X,30HSECTION GEOMETRY SPECIFICATION,//,10X,10HSTREAM
   1LINE,2X,5HINLET,5X,6HOUTLET,4X,6HY2 LE/,4X,6HY2 TE/,3X,48HLE RADIU
   2S MAX THICK TE THICK  POINT OF  CHORD OR,3X,7HX STACK,3X,7HY STACK
   3,/,11X,6HNUMBER,5X,5HANGLE,5X,5HANGLE,3X, 19HMAX VALUE MAX VALUE,3
   4X,6H/CHORD,4X,6H/CHORD,3X,8H/2*CHORD,2X,18HMAX THICK AXIAL CD,4X,6
   5HOFFSET,4X,6HOFFSET,//,(10X,F7.2,3X,F8.3,F10.3,2F10.4,3F10.5,2F10.
   64,F11.6,F10.6))
    GO TO 150
110 IF(LNCT.LE.50-2*NSPEC)GO TO 120
    WRITE(LOG2,40)
    LNCT=1
120 LNCT=LNCT+10+2*NSPEC
    READ(LOG1,130)  (ZR(J),B1(J),B2(J),PP(J),QQ(J),RLE(J),TC(J),TE(J),Z
   1Z(J),CORD(J),DELX(J),DELY(J),S(J),BS(J),J=1,NSPEC)
130 FORMAT(6F12.0,/,6F12.0,/,2F12.0)
    WRITE(LOG2,100)(ZR(J),B1(J),B2(J),PP(J),QQ(J),RLE(J),TC(J),TE(J),Z
   1Z(J),CORD(J),DELX(J),DELY(J),J=1,NSPEC)
    IF(ISECN.EQ.1) WRITE(LOG2,140)(ZR(J),S(J),BS(J),J=1,NSPEC)
140 FORMAT(2X,/,10X,34HSTREAMLINE  INFLECTION  INFLECTION,/,11X,6HNUMB
   1ER,8X,5HPOINT,7X,5HANGLE,//,(10X,F7.2,F14.5,F11.3))
    IF(ISECN.EQ.3) WRITE(LOG2,145)(ZR(J),S(J),BS(J),J=1,NSPEC)
145 FORMAT(2X,/,10X,46HSTREAMLINE  TRANSITION  DEL ANGLE,
   1 /,11X,6HNUMBER,8X,5HPOINT,6X,7HFROM LE,//,(10X,F7.2,F14.5,F11.3))
150 IF(IFPLOT.EQ.0.OR.IFPLOT.EQ.4) GO TO 160
    IKDUM=0
    IF(B1(1).LT.0.0) IKDUM=1
    IF(IFPLOT.EQ.1.OR.IFPLOT.EQ.3) CALL FQ(ISTAK,PLTSZE,1,TITLE,IKDUM)
```

```
160 DO 430 J=1,NLINES
    DO 170 I=1,NSTNS
    KPT=KPTS(I)
170 CALL D1(RSTA(1,I),XSTA(1,I),KPT,R(I,J),XHERE(I),1,0)
    X(1)=XHERE(1)
    X(100)=XHERE(NSTNS)
    AX=(X(100)-X(1))/99.0
    DO 180 I=2,99
180 X(I)=X(I-1)+AX
    CALL CQ(XHERE,R(1,J),NSTNS,X,XDUM,YPRIME,100,1)
    CALL CQ(XHERE,R(1,J),NSTNS,XHERE,XDUM,TANPHI(1,J),NSTNS,1)
    SS(1)=0.0
    DO 190 I=2,100
190 SS(I)=SS(I-1)+AX*SQRT(1.0+((YPRIME(I)+YPRIME(I-1))/2.0)**2)
    XJ=J
    CALL D1(ZR,B1  ,NSPEC,XJ,BETA1,1,0)
    CALL D1(ZR,B2  ,NSPEC,XJ,BETA2,1,0)
    CALL D1(ZR,PP  ,NSPEC,XJ,P    ,1,0)
    CALL D1(ZR,QQ  ,NSPEC,XJ,Q    ,1,0)
    CALL D1(ZR,RLE ,NSPEC,XJ,YZERO,1,0)
    CALL D1(ZR,TC  ,NSPEC,XJ,T    ,1,0)
    CALL D1(ZR,TE  ,NSPEC,XJ,YONE ,1,0)
    CALL D1(ZR,DELX,NSPEC,XJ,XDEL ,1,0)
    CALL D1(ZR,DELY.NSPEC,XJ,YDEL ,1,0)
    CALL D1(ZR,ZZ  ,NSPEC,XJ,Z    ,1,0)
    CALL D1(ZR,CORD,NSPEC,XJ,CHD  ,1,0)
    IF(ISECN.EQ.0.OR.ISECN.EQ.2) GO TO 200
    CALL D1(ZR,S   ,NSPEC,XJ,SQ   ,1,0)
    CALL D1(ZR,BS  ,NSPEC,XJ,SB   ,1,0)
200 CALL D1(X,SS,100,STACKX,BX,1,1)
    CALL BQ(J,YS,YP,XS,XP,YSEMI,XSEMI,LOG1,LOG2,NPOINT,IPRINT,BETA1,BE
   1TA2,P,Q,YZERO,T,YONE,XDEL,YDEL,Z,CHD,LNCT,IFCORD,SQ,SB,ISECN,
   2 XSEMJ,YSEMJ,ISTAK,XHERE,X,SS,NSTNS,R,XTEMP,YPRIME,RAD,EPZ,BX,SIGM
   3A)
    CALL D1(X,SS,100,STACKX,BX,1,1)
    DO 210 I=1,100
    X(I)=X(I)-STACKX
210 SS(I)=SS(I)-BX
    DO 220 I=1,NSTNS
220 XHERE(I)=XHERE(I)-STACKX
```

```
      IF(IFPLOT.EQ.0.OR.IFPLOT.EQ.2.OR.IFPLOT.EQ.4)GO TO 260
      XPLOT=XS(J,1)*SCALE
      YPLOT=YS(J,1)*SCALE
      CALL PLOT(XPLOT,YPLOT,3)
      DO 230 I=2,NPOINT
      XPLOT=XS(J,I)*SCALE
      YPLOT=YS(J,I)*SCALE
  230 CALL PLOT(XPLOT,YPLOT,2)
      IF(ISECN.NE.2) GO TO 233
      DO 231 I=2,30
      XPLOT=XSEMJ(J,I)*SCALE
      YPLOT=YSEMJ(J,I)*SCALE
  231 CALL PLOT(XPLOT,YPLOT,2)
  233 DO 240 II=1,NPOINT
      I=NPOINT-II+1
      XPLOT=XP(J,I)*SCALE
      YPLOT=YP(J,I)*SCALE
  240 CALL PLOT(XPLOT,YPLOT,2)
      DO 250 I=2,30
      XPLOT=XSEMI(J,I)*SCALE
      YPLOT=YSEMI(J,I)*SCALE
  250 CALL PLOT(XPLOT,YPLOT,2)
      XPLOT=XS(J,1)*SCALE
      YPLOT=YS(J,1)*SCALE
      CALL PLOT(XPLOT,YPLOT,2)
  260 IJDUM=0
      DO 261 I=1,NSTNS
      IF(IFANGS(I).EQ.1) IJDUM=1
  261 CONTINUE
      IF(IJDUM.EQ.0) GO TO 263
      CALL D1(SS,X,100,XTEMP,XTEMP,100,1)
      DO 262 I=1,NSTNS
      CALL D1(XTEMP,SIGMA ,100,XHERE(I),THETA(J,I),1,1)
      CALL D1(XTEMP,YPRIME,100,XHERE(I),ALPHA(J,I),1,1)
      ZCAMB(J,I)=R(I,J)*COS(THETA(J,I))
  262 YCAMB(J,I)=R(I,J)*SIN(THETA(J,I))
  263 DO 270 I=1,NPOINT
  270 XTEMP(I)=XS(J,I)
      CALL D1(SS,X,100,XTEMP,XTEMP,NPOINT,1)
      CALL D1(XHERE,R(1,J),NSTNS,XTEMP,RAD,NPOINT,0)
```

```
      K=1
      DO 280 I=1,NPOINT
      EPS=EPZ( I, K)
      ZS(J,I)=RAD(I)*COS(EPS)
      YS(J,I)=RAD(I)*SIN(EPS)
  280 XS(J,I)=XTEMP(I)
      DO 290 I=1,NPOINT
  290 XTEMP(I)=XP(J,I)
      CALL D1(SS,X,100,XTEMP,XTEMP,NPOINT,1)
      CALL D1(XHERE,R(1,J),NSTNS,XTEMP,RAD,NPOINT,0)
      K=2
      DO 300 I=1,NPOINT
      EPS=EPZ( I, K)
      ZP(J,I)=RAD(I)*COS(EPS)
      YP(J,I)=RAD(I)*SIN(EPS)
  300 XP(J,I)=XTEMP(I)
      DO 310 I=1,31
  310 XTEMP(I)=XSEMI(J,I)
      CALL D1(SS,X,100,XTEMP,XTEMP,31,1)
      CALL D1(XHERE,R(1,J),NSTNS,XTEMP,RAD,31,0)
      K=3
      DO 320 I=1,31
      EPS=EPZ( I, K)
      ZSEMI(J,I)=RAD(I)*COS(EPS)
      YSEMI(J,I)=RAD(I)*SIN(EPS)
  320 XSEMI(J,I)=XTEMP(I)
      IF(ISECN.NE.2) GO TO 324
      DO 321 I=1,31
  321 XTEMP(I)=XSEMJ(J,I)
      CALL D1(SS,X,100,XTEMP,XTEMP,31,1)
      CALL D1(XHERE,R(1,J),NSTNS,XTEMP,RAD,31,0)
      K=4
      DO 322 I=1,31
      EPS=EPZ( I, K)
      ZSEMJ(J,I)=RAD(I)*COS(EPS)
      YSEMJ(J,I)=RAD(I)*SIN(EPS)
  322 XSEMJ(J,I)=XTEMP(I)
  324 IF(IPRINT.EQ.2)GO TO 430
      IF(LNCT.LE.50)GO TO 330
      WRITE(LOG2,40)
```

```
      LNCT=1
  330 LNCT=LNCT+5
      WRITE(LOG2,340)J
  340 FORMAT(2X,/,10X,38HCARTESIAN COORDINATES ON STREAMSURFACE,I3,//,10
     1X,8HPOINT NO,5X,2HZS,12X,2HXS,12X,2HYS,16X,2HZP,12X,2HXP,12X,2HYP
     2,/,2X)
      I=1
  350 WRITE(LOG2,360)I,ZS(J,I),XS(J,I),YS(J,I),ZP(J,I),XP(J,I),YP(J,I)
  360 FORMAT(10X,I5,3X,1P3E14.5,4X,1P3E14.5)
      I=I+1
      LNCT=LNCT+1
      IF(I.GT.NPOINT)GO TO 380
      IF(LNCT.LE.59)GO TO 350
      WRITE(LOG2,370)
  370 FORMAT(1H1,9X,8HPOINT NO,5X,2HZS,12X,2HXS,12X,2HYS,16X,2HZP,12X,2H
     1XP,12X,2HYP,/,2X)
      LNCT=2
      GO TO 350
  380 IF(LNCT.LE.50)GO TO 390
      WRITE(LOG2,40)
      LNCT=1
  390 LNCT=LNCT+3
       IF(ISECN.NE.2) GO TO 395
      GO TO 421
  395 WRITE(LOG2,400)
  400 FORMAT(2X,/,10X,8HPOINT NO,4X,5HZSEMI,9X,5HXSEMI,9X,5HYSEMI,/,2X)
  401 FORMAT(2X,/,10X,8HPOINT NO,4X,5HZSEMI,9X,5HXSEMI,9X,5HYSEMI,13X,
     1 5HZSEMJ,9X,5HXSEMJ,9X,5HYSEMJ,/,2X)
      I=1
  410 WRITE(LOG2,420)I,ZSEMI(J,I),XSEMI(J,I),YSEMI(J,I)
  420 FORMAT(10X,I5,3X,1P3E14.5)
      GO TO 428
  421 WRITE(LOG2,401)
      I=1
  425 WRITE(LOG2,427) I,ZSEMI(J,I),XSEMI(J,I),YSEMI(J,I),ZSEMJ(J,I),
     1 XSEMJ(J,I),YSEMJ(J,I)
  427 FORMAT(10X,I5,3X,1P3E14.5,4X,1P3E14.5)
  428 I=I+1
      LNCT=LNCT+1
      IF(I.GT.31) GO TO 430
```

```
      IF(LNCT.LE.59.AND.ISECN.EQ.2) GO TO 425
      IF(ISECN.NE.2) GO TO 429
      WRITE(LOG2,40)
      WRITE(LOG2,401)
      LNCT=4
      GO TO 425
  429 IF(LNCT.LE.59)GO TO 410
      WRITE(LOG2,40)
      WRITE(LOG2,400)
      LNCT=4
      GO TO 410
  430 CONTINUE
      IF(IPRINT.EQ.1)GO TO 470
      VOL=0.0
      DO 440 J=2,NLINES
      VOL=VOL+(((XS(J,1)-XP(J,1))**2+(YS(J,1)-YP(J,1))**2)+((XS(J-1,1)-X
     1P(J-1,1))**2+(YS(J-1,1)-YP(J-1,1))**2))*(ZS(J,1)+ZP(J,1)-ZS(J-1,1)
     2-ZP(J-1,1))*PI/32.0
      DO 440 I=2,NPOINT
  440 VOL=VOL+((SQRT((XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2)+SQRT((XS
     1(J,I-1)-XP(J,I-1))**2+(YS(J,I-1)-YP(J,I-1))**2))*(SQRT((XS(J,I-1)-
     2XS(J,I))**2+(YS(J,I-1)-YS(J,I))**2)+SQRT((XP(J,I-1)-XP(J,I))**2+(Y
     3P(J,I-1)-YP(J,I))**2))+(SQRT((XS(J-1,I)-XP(J-1,I))**2+(YS(J-1,I)-Y
     4P(J-1,I))**2)+SQRT((XS(J-1,I-1)-XP(J-1,I-1))**2+(YS(J-1,I-1)-YP(J-
     51,I-1))**2))*(SQRT((XS(J-1,I-1)-XS(J-1,I))**2+(YS(J-1,I-1)-YS(J-1,
     6I))**2)+SQRT((XP(J-1,I-1)-XP(J-1,I))**2+(YP(J-1,I-1)-YP(J-1,I))**2
     7)))*(ZS(J,I)+ZS(J,I-1)+ZP(J,I)+ZP(J,I-1)-ZS(J-1,I)-ZS(J-1,I-1)-ZP(
     8J-1,I)-ZP(J-1,I-1))/32.0
      IF(LNCT.LE.56)GO TO 450
      LNCT=1
      WRITE(LOG2,40)
  450 LNCT=LNCT+4
      WRITE(LOG2,458) VOL
  458 FORMAT(2X,/,2X,/,40X,25HVOLUME OF BLADE SECTION =,1PE11.4,/,40X,36
     1(1H*))
      IF(IJDUM.EQ.0) GO TO 470
      WRITE(LOG2,40)
      WRITE(LOG2,459)
  459 FORMAT(43X,43HBLADE CALCULATIONS FOR AERODYNAMIC ANALYSIS,/,43X,
     1 43(1H*))
```

```
      IDUM=7
      LNCT=3
      DO 469 I=1,NSTNS
      IF(IFANGS(I).EQ.0) GO TO 469
      DO 462 J=1,NLINES
      CALL D1(RSTA(1,I),XSTA(1,I).KPTS(I),R(I,J),XDUM,1,0)
      CALL CQ(RSTA(1,I),XSTA(1,I),KPTS(I),R(I,J),XDUM,ZR(J),1,1)
      DO 461 K=1,NPOINT
      SS    (K)=XS(J,K)
      RAD   (K)=YS(J,K)
      XTEMP(K)=XP(J,K)
  461 X     (K)=YP(J,K)
      XDUM=XDUM-STACKX
      CALL D1(SS   ,RAD  ,NPOINT,XDUM,YY1,1,1)
      CALL D1(XTEMP,X    ,NPOINT,XDUM,YY2,1,1)
      W1=YY1/R(I,J)
      W2=YY2/R(I,J)
      TC(J)=ABS(ATAN(W1/SQRT(1.-W1**2))-ATAN(W2/SQRT(1.-W2**2)))/(2.*PI)
     1 *FLOAT(NBLADE)
  462 CONTINUE
      CALL CQ(ZCAMB(1,I),YCAMB(1,I),NLINES,ZCAMB(1,I),XDUM,RLE,NLINES,1)
      IF(LNCT+IDUM+NLINES.LE.59) GO TO 463
      WRITE(LOG2,40)
      LNCT=2
  463 LNCT=LNCT+IDUM+NLINES
      WRITE(LOG2,464) I,NLINES
  464 FORMAT(///,48X, 8HSTATION ,I2, 5X,17HNUMBER OF RADII= ,I2,//,36X,
     1 6HRADIUS,5X,7HSECTION,6X, 4HLEAN,9X,5HBLADE,7X,5HTHETA,/,48X,
     2 5HANGLE,6X,5HANGLE,7X,8HBLOCKAGE,/,2X)
      DO 465 J=1,NLINES
      EPS=(THETA(J,I)-ATAN(RLE(J)))*C1
      ALPHB=ALPHA(J,I)
      ALP=(ATAN((TANPHI(I,J)*TAN(EPS/C1)+ALPHB*SQRT(1.+TANPHI(I,J)**2))/
     1 (1.-TANPHI(I,J)*ZR(J))))*C1
      WRITE(LOG2,466) R(I,J),ALP,EPS,TC(J),THETA(J,I)
      IF(IPUNCH.EQ.0) GO TO 465
      WRITE(LOG3,467) R(I,J),ALP,EPS,TC(J),THETA(J,I),I,J
  465 CONTINUE
  466 FORMAT(30X,5F12.4)
  467 FORMAT(5F12.7,2I3)
```

```
469 CONTINUE
470 IF(IFPLOT.LT.2.OR.IFPLOT.EQ.4)GO TO 480
    CALL FQ(ISTAK,PLTSZE,2,TITLE,IKDUM)
480 IF(IPRINT.EQ.1)GO TO 500
    LNCT=2
    WRITE(LOG2,490)
490 FORMAT(1H1,27X,74HBLADE SURFACE GEOMETRY IN CARTESIAN COORDINATES
   1AT SPECIFIED VALUES OF 'Z',/,28X,74H********************************
   2******************************************)
500 IF(IPRINT.EQ.1.AND.IFPLOT.LE.1)GO TO 780
    XZ=NZ-1
    DZ=(ZOUTER-ZINNER)/XZ
    ZOUT(1)=ZINNER
    DO 510 J=3,NZ
510 ZOUT(J-1)=ZOUT(J-2)+DZ
    ZOUT(NZ)=ZOUTER
    DO 520 I=1,NPOINT
    CALL D1(ZS(1,I),XS(1,I),NLINES,ZOUT,TEMP1,NZ,0)
    CALL D1(ZS(1,I),YS(1,I),NLINES,ZOUT,TEMP2,NZ,0)
    CALL D1(ZP(1,I),XP(1,I),NLINES,ZOUT,TEMP3,NZ,0)
    CALL D1(ZP(1,I),YP(1,I),NLINES,ZOUT,TEMP4,NZ,0)
    DO 520 J=1,NZ
    XS(J,I)=TEMP1(J)
    YS(J,I)=TEMP2(J)
    XP(J,I)=TEMP3(J)
520 YP(J,I)=TEMP4(J)
    DO 530 I=1,31
    CALL D1(ZSEMI(1,I),XSEMI(1,I),NLINES,ZOUT,TEMP1,NZ,0)
    CALL D1(ZSEMI(1,I),YSEMI(1,I),NLINES,ZOUT,TEMP2,NZ,0)
    DO 530 J=1,NZ
    XSEMI(J,I)=TEMP1(J)
530 YSEMI(J,I)=TEMP2(J)
    IF(ISECN.NE.2) GO TO 535
    DO 533 I=1,31
    CALL D1(ZSEMJ(1,I),XSEMJ(1,I),NLINES,ZOUT,TEMP1,NZ,0)
    CALL D1(ZSEMJ(1,I),YSEMJ(1,I),NLINES,ZOUT,TEMP2,NZ,0)
    DO 533 J=1,NZ
    XSEMJ(J,I)=TEMP1(J)
533 YSEMJ(J,I)=TEMP2(J)
535 DO 770 J=1,NZ
```

```
      RD =SQRT((XS(J,1)-XP(J,1))**2+(YS(J,1)-YP(J,1))**2)/2.0
      AREA=PI*RD **2/2.0
      BETA1=ATAN((YS(J,2)+YP(J,2)-YS(J,1)-YP(J,1))/(XS(J,2)+XP(J,2)-XS(J
     1,1)-XP(J,1)))
      XINT=AREA*((XP(J,1)+XS(J,1))/2.0-COS(BETA1)*4.0/(3.0*PI)*RD )
      YINT=AREA*((YP(J,1)+YS(J,1))/2.0-SIN(BETA1)*4.0/(3.0*PI)*RD )
      IF(ISECN.NE.2) GO TO 538
      N1=NPOINT
      N=N1
      N2=N1-1
      BETA2=ATAN((YS(J,N1)+YP(J,N1)-YS(J,N2)-YP(J,N2))/(XS(J,N1)+
     1 XP(J,N1)-XS(J,N2)-XP(J,N2)))
      XINT=XINT+AREA*((XP(J,N)+XS(J,N))/2.+COS(BETA2)*4./(3.*PI)*RD)
      YINT=YINT+AREA*((YP(J,N)+YS(J,N))/2.+SIN(BETA2)*4./(3.*PI)*RD)
      AREA=2.*AREA
  538 DO 540 I=2,NPOINT
      DELA=(SQRT((XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2)+SQRT((XS(J,I
     1-1)-XP(J,I-1))**2+(YS(J,I-1)-YP(J,I-1))**2))*(SQRT((XS(J,I-1)-XS(J
     2,I))**2+(YS(J,I-1)-YS(J,I))**2)+SQRT((XP(J,I-1)-XP(J,I))**2+(YP(J,
     3I-1)-YP(J,I))**2))/4.0
      AREA=AREA+DELA
      XINT=XINT+DELA*(XS(J,I)+XS(J,I-1)+XP(J,I)+XP(J,I-1))/4.0
  540 YINT=YINT+DELA*(YS(J,I)+YS(J,I-1)+YP(J,I)+YP(J,I-1))/4.0
      YINT=YINT/AREA
      XINT=XINT/AREA
      X1=(XS(J,1)+XP(J,1))/2.
      Y1=(YS(J,1)+YP(J,1))/2.
      T1=SQRT((XS(J,1)-XP(J,1))**2+(YS(J,1)-YP(J,1))**2)
      F=0.
      U=0.
      DO 545 I=2,NPOINT
      T2=SQRT((XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2)
      X2=(XS(J,I)+XP(J,I))/2.
      Y2=(YS(J,I)+YP(J,I))/2.
      DELU=SQRT((X2-X1)**2+(Y2-Y1)**2)
      U=U+DELU
      TAV3=(T1**3+T2**3)/2.
      F=F+TAV3*DELU
      X1=X2
      Y1=Y2
```

```
  545 T1=T2
      TORCON=((1./3.)*F)/(1.+(4./3.)*F/AREA/U**2)
      IX=0.0
      IY=0.0
      IXY=0.0
      DO 550 I=2,NPOINT
      XD=(SQRT((XS(J,I-1)-XP(J,I-1))**2+(YS(J,I-1)-YP(J,I-1))**2)+SQRT((
     1XS(J,I)-XP(J,I))**2+(YS(J,I)-YP(J,I))**2))/2.0
      YD=(SQRT((XS(J,I)-XS(J,I-1))**2+(YS(J,I)-YS(J,I-1))**2)+SQRT((XP(J
     1,I)-XP(J,I-1))**2+(YP(J,I)-YP(J,I-1))**2))/2.0
      IXD=YD*YD*YD*XD/12.0
      IYD=XD*XD*XD*YD/12.0
      ANG=ATAN((YS(J,I)+YP(J,I)-YS(J,I-1)-YP(J,I-1))/(XP(J,I)+XS(J,I)-XP
     1(J,I-1)-XS(J,I-1)))
      COSANG=COS(2.0*ANG)
      IXN=(IXD+IYD+(IXD-IYD)*COSANG)/2.0
      IYN=(IXD+IYD-(IXD-IYD)*COSANG)/2.0
      IXYN=0.0
      IF(ANG.NE.0.0)IXYN=((IXN-IYN)*COSANG-IXD+IYD)/(2.0*SIN(2.0*ANG))
      DELA=XD*YD
      YMN=(YS(J,I)+YS(J,I-1)+YP(J,I)+YP(J,I-1))/4.0-YINT
      XMN=(XS(J,I)+XS(J,I-1)+XP(J,I)+XP(J,I-1))/4.0-XINT
      IX=IX+IXN+DELA*YMN*YMN
      IY=IY+IYN+DELA*XMN*XMN
  550 IXY=IXY+IXYN+DELA*YMN*XMN
      ANG=ATAN(2.0*IXY/(IY-IX))
      IPX=(IX+IY)/2.0+(IX-IY)/2.0*COS(ANG)-IXY*SIN(ANG)
      IPY=(IX+IY)/2.0-(IX-IY)/2.0*COS(ANG)+IXY*SIN(ANG)
      ANG=ANG/2.0*C1
      IF(IPRINT.EQ.1)GO TO 570
      IF(LNCT.LE.45)GO TO 560
      WRITE(LOG2,40)
      LNCT=1
  560 LNCT=LNCT+16
      WRITE(LOG2,570) J,ZOUT(J),AREA,XINT,YINT,IX,IY,IXY,IPX,ANG,IPY,ANG
  570 FORMAT(2X,/,50X,14HSECTION NUMBER,I3,3X,5H'Z' =,F9.4,/,50X,34H****
     1******************************,///,20X,18HSECTION PROPERTIES,7X,12
     2HSECTION AREA,26X,1H=,1PE12.4,//,45X,20HLOCATION OF CENTROID,11X,4
     3HXBAR,3X,1H=,E12.4,/,45X,22HRELATIVE TO STACK AXIS,9X,4HYBAR,3X,1H
     4=,E12.4,//,45X,22HSECOND MOMENTS OF AREA,9X,2HIX,5X,1H=,E12.4,/,45
```

```
     5X,14HABOUT CENTROID,17X,2HIY,5X,1H=,E12.4,/,76X,3HIXY,4X,1H=,E12.4
     6,//,45X,24HPRINCIPAL SECOND MOMENTS,7X,3HIPX,4X,1H=,E12.4,4H (AT,0
     7PF7.2,21H DEGREES TO 'X' AXIS),/,45X,22HOF AREA ABOUT CENTROID,9X,
     83HIPY,4X,1H=,1PE12.4,4H (AT,0PF7.2,21H DEGREES TO 'Y' AXIS))
      WRITE(LOG2,571) TORCON
  571 FORMAT(/,45X,18HTORSIONAL CONSTANT,20X,1H=,1PE12.4,/,2X)
      LNCT=LNCT+3
      IF(LNCT.LE.50)GO TO 580
      WRITE(LOG2,40)
      LNCT=1
  580 LNCT=LNCT+5
      WRITE(LOG2,590)
  590 FORMAT(2X,/,20X,19HSECTION COORDINATES,/,2X)
      WRITE(LOG2,600)
  600 FORMAT(31X,8HPOINT NO,5X,2HXS,12X,2HYS,16X,2HXP,12X,2HYP,/,2X)
      DO 610 I=1,NPOINT
      LNCT=LNCT+1
      IF(LNCT.LE.60)GO TO 610
      LNCT=4
      WRITE(LOG2,40)
      WRITE(LOG2,600)
  610 WRITE(LOG2,620)I,XS(J,I),YS(J,I),XP(J,I),YP(J,I)
  620 FORMAT(31X,I5,3X,1P2E14.5,4X,2E14.5)
      IF(LNCT.LE.55)GO TO 630
      LNCT=1
      WRITE(LOG2,40)
  630 LNCT=LNCT+3
      IF(ISECN.EQ.2) WRITE(LOG2,641)
      IF(ISECN.EQ.2) GO TO 642
      WRITE(LOG2,640)
  640 FORMAT(2X,/,31X,8HPOINT NO,5X,5HXSEMI,9X,5HYSEMI,/,2X)
  641 FORMAT(2X,/,31X,8HPOINT NO,5X,5HXSEMI,9X,5HYSEMI,12X,5HXSEMJ,9X,
     1 5HYSEMJ,/,2X)
  642 DO 650 I=1,31
      LNCT=LNCT+1
      IF(LNCT.LE.60) GO TO 647
      WRITE(LOG2,40)
      IF(ISECN.EQ.2) WRITE(LOG2,641)
      IF(ISECN.EQ.2) GO TO 645
      WRITE(LOG2,640)
```

```
645 LNCT=4
647 IF(ISECN.EQ.2) WRITE(LOG2,620) I,XSEMI(J,I),YSEMI(J,I),XSEMJ(J,I),
   1 YSEMJ(J,I)
    IF(ISECN.EQ.2) GO TO 650
    WRITE(LOG2,660) I,XSEMI(J,I),YSEMI(J,I)
650 CONTINUE
660 FORMAT(31X,I5,3X,1P2E14.5)
670 IF(IFPLOT.LT.2)GO TO 770
    IF(IFPLOT.EQ.4)GO TO 710
    XPLOT=XS(J,1)*SCALE
    YPLOT=YS(J,1)*SCALE
    CALL PLOT(XPLOT,YPLOT,3)
    DO 680 I=2,NPOINT
    XPLOT=XS(J,I)*SCALE
    YPLOT=YS(J,I)*SCALE
680 CALL PLOT(XPLOT,YPLOT,2)
    IF(ISECN.NE.2) GO TO 686
    DO 685 I=2,30
    XPLOT=XSEMJ(J,I)*SCALE
    YPLOT=YSEMJ(J,I)*SCALE
685 CALL PLOT(XPLOT,YPLOT,2)
686 DO 690 II=1,NPOINT
    I=NPOINT+1-II
    XPLOT=XP(J,I)*SCALE
    YPLOT=YP(J,I)*SCALE
690 CALL PLOT(XPLOT,YPLOT,2)
    DO 700 I=2,30
    XPLOT=XSEMI(J,I)*SCALE
    YPLOT=YSEMI(J,I)*SCALE
700 CALL PLOT(XPLOT,YPLOT,2)
    XPLOT=XS(J,1)*SCALE
    YPLOT=YS(J,1)*SCALE
    CALL PLOT(XPLOT,YPLOT,2)
    GO TO 770
710 CALL SYMBOL(15.4,0.0,0.35,22HCARTESIAN SECTION NO. ,0.0,22)
    XJ=J
    CALL NUMBER(23.0,0.0,0.35,XJ,0.0,-1)
    CALL SYMBOL(24.5,0.0,0.35,10HSTAGGER = ,0.0,10)
    STAGER=ATAN((YS(J,NPOINT)+YP(J,NPOINT)-YS(J,1)-YP(J,1))/(XS(J,NPOI
   1NT)+XP(J,NPOINT)-XS(J,1)-XP(J,1)))*C1
```

```
      CALL NUMBER(28.0,0.0,0.35,STAGER,0.0,3)
      CALL PLOT(22.0,5.25,-3)
      SINSTG=SIN(STAGER/C1)
      COSSTG=COS(STAGER/C1)
      YPLOT=4.75
      XPLOT=4.75*SINSTG/COSSTG
      IF(ABS(XPLOT).LE.22.0)GO TO 720
      XPLOT=22.0
      YPLOT=-22.0/SINSTG*COSSTG
  720 CALL PLOT(XPLOT,YPLOT,3)
      XPLOT=-XPLOT
      YPLOT=-YPLOT
      CALL PLOT(XPLOT,YPLOT,2)
      XPLOT=22.0
      YPLOT=-22.0*SINSTG/COSSTG
      IF(ABS(YPLOT).LE.4.75)GO TO 730
      YPLOT=-4.75
      XPLOT=4.75/SINSTG*COSSTG
  730 CALL PLOT(XPLOT,YPLOT,3)
      XPLOT=-XPLOT
      YPLOT=-YPLOT
      CALL PLOT(XPLOT,YPLOT,2)
      XPLOT=SCALE*(XS(J,1)*COSSTG+YS(J,1)*SINSTG)
      YPLOT=SCALE*(YS(J,1)*COSSTG-XS(J,1)*SINSTG)
      CALL PLOT(XPLOT,YPLOT,3)
      DO 740 I=2,NPOINT
      XPLOT=SCALE*(XS(J,I)*COSSTG+YS(J,I)*SINSTG)
      YPLOT=SCALE*(YS(J,I)*COSSTG-XS(J,I)*SINSTG)
  740 CALL PLOT(XPLOT,YPLOT,2)
      IF(ISECN.NE.2) GO TO 742
      DO 741 I=2,30
      XPLOT=SCALE*(XSEMJ(J,I)*COSSTG+YSEMJ(J,I)*SINSTG)
      YPLOT=SCALE*(YSEMJ(J,I)*COSSTG-XSEMJ(J,I)*SINSTG)
  741 CALL PLOT(XPLOT,YPLOT,2)
  742 DO 750 II=1,NPOINT
      I=NPOINT+1-II
      XPLOT=SCALE*(XP(J,I)*COSSTG+YP(J,I)*SINSTG)
      YPLOT=SCALE*(YP(J,I)*COSSTG-XP(J,I)*SINSTG)
  750 CALL PLOT(XPLOT,YPLOT,2)
      DO 760 I=2,30
```

```
      XPLOT=SCALE*(XSEMI(J,I)*COSSTG+YSEMI(J,I)*SINSTG)
      YPLOT=SCALE*(YSEMI(J,I)*COSSTG-XSEMI(J,I)*SINSTG)
  760 CALL PLOT(XPLOT,YPLOT,2)
      XPLOT=SCALE*(XS(J,1)*COSSTG+YS(J,1)*SINSTG)
      YPLOT=SCALE*(YS(J,1)*COSSTG-XS(J,1)*SINSTG)
      CALL PLOT(XPLOT,YPLOT,2)
      CALL PLOT(23.0,-5.25,-3)
  770 CONTINUE
  780 IF(IFPLOT.NE.0)CALL PLOTE
      STOP
      END
```

```
      SUBROUTINE BQ(IBL,YS,YP,XS,XP,YSEMI,XSEMI,LOG1,LOG2,N,IPRINT,BETA1
     1,BETA2,P,Q,YZERO,T,YONE,XDEL,YDEL,Z,AXIALC,LNCT,IFCORD,SQ,SB,ISECN
     2,XSEMJ,YSEMJ,ISTAK,XHERE,X,SS,NSTNS,R,DX,Y,DY,SS1,BX,SIGMA)
      REAL IX,IY,IXY,IPX,IPY,IXD,IYD,IXN,IYN,IXYN
      DIMENSION YS(15, 80), YP(15, 80), XS(15, 80), XP(15, 80), YSEMI(15
     1,31), XSEMI(15,31),S( 80), PHI(11), THICK2( 80), XM( 81), YM( 80),
     2 AM( 80), XSEMJ(15,31), YSEMJ(15,31), XHERE(100), X(100), SS(100),
     3 R(10,15), DX(100), DY(100), SS1( 80,4), Y(100), SIGMA(100)
      F1(A)=A*EXP(1.0-A*SQ)*SQ
      F2(A)=(SQ-1.0)*A*EXP(1.0+A*(1.0-SQ))
      F3(A,B,C,D)=B/A**3*EXP(A*XD)*(A*XD-2.0)+C*(XD+SQ)+D
      F4(A,B)=ABS(A-B)/(A-B)
      F5(A,B,C)=B/A**2*EXP(A*XD)*(A*XD-1.0)+C
      F6(XAB)=SQRT(RDIUS**2-(XAB-X1)**2)+Y1
      F7(XAB)=-SQRT(RDIUS**2-(XAB-X1)**2)+Y1
      F8(XAB)=-1./SQRT(RDIUS**2-(XAB-X1)**2)*(XAB-X1)
   10 FORMAT(1H1)
      BTA1=BETA1
      BTA2=BETA2
      PI=3.14159265
      C1=180./PI
      IF(IPRINT.EQ.0)GO TO 40
      WRITE(LOG2,20) IBL,P,Q,BETA1,BETA2,YZERO,T,YONE,Z,AXIALC
   20 FORMAT(1H1,44X,43HSTREAMSURFACE GEOMETRY ON STREAMLINE NUMBER,I3,/
     145X46H**********************************************//,20X,1HP,15X
     2,1H=,F7.4,6X,72H(D2YDX2 OF MEANLINE AT LEADING EDGE AS A FRACTION
     3OF ITS MAXIMUM VALUE.),/,20X,1HQ,        15X,1H=,F7.4,6X,73H(D2YDX
     42 OF MEANLINE AT TRAILING EDGE AS A FRACTION OF ITS MAXIMUM VALUE.
     5),/,20X,5HBETA1,11X1H=,F7.3,6X,20H(BLADE INLET ANGLE.),/,20X,5HBET
     6A2,11X,1H=,F7.3,6X,21H(BLADE OUTLET ANGLE.),/,20X,5HYZERO,11X,1H=,
     7F8.5,5X,51H(BLADE LEADING EDGE RADIUS AS A FRACTION OF CHORD.),/,2
     80X,1HT,15X,1H=,F8.5,5X,49H(BLADE MAXIMUM THICKNESS AS A FRACTION O
     9F CHORD.),/,20X,4HYONE,12X,1H=,F8.5,5X,60H(BLADE TRAILING EDGE HAL
     AF-THICKNESS AS A FRACTION OF CHORD.),/,20X,1HZ,15X,1H=,F7.4,6X,59H
     B(LOCATION OF MAXIMUM THICKNESS AS A FRACTION OF MEAN LINE.)  ,/,20
     CX,4HCORD,12X,1H=,F7.4,6X,39H(CHORD OR MERIDIONAL CHORD OF SECTION.
     D))
      IF(ISECN.EQ.1.OR.ISECN.EQ.3) WRITE(LOG2,30)SQ,SB
   30 FORMAT(20X,1HS,15X,1H=,F7.4,6X,53H(INFLECTION POINT AS A FRACTION
     1OF MERIDIONAL CHORD.)/,20X,5HBETA3,11X,1H=,F7.3,6X,36H(CHANGE IN A
```

```
  2NGLE FROM LEADING EDGE.))
40 IF(ISECN.EQ.1)GO TO 50
   IF(ISECN.EQ.3) GO TO 112
   IF(ISECN.EQ.2) GO TO 115
   H=1.0/(1.0+SQRT((1.0-Q)/(1.0-P)))
   OA=4.0*(TAN(BETA1/C1)-TAN(BETA2/C1))/(P/(1.0-P)*H*H+H-1.0/3.0)
   OA48=OA/48.0
   XK2=-H*H/(8.0*(1.0-P))*OA
   B=H*H*H/12.0*OA+TAN(BETA1/C1)
   C=-H*H*H*H*OA48
   XMLC=SQRT(1.0+(OA48*(1.0-H)**4+XK2+B+C)**2)
   GO TO 120
50 NQ=1
   S3=BETA1+SB
   G1=1.0/SQ
   R1=F1(G1)
   G2=G1+5.0
   R2=F1(G2)
   S2=F4(R2,P)
60 G3=G2+(P-R2)*(G2-G1)/(R2-R1)
   R3=F1(G3)
   S3=F4(R3,P)
   IF(ABS(R3-P).LE.0.0001)GO TO 80
   IF(NQ.GT.50)GO TO 590
   NQ=NQ+1
   IF(ABS(S2-S3).LE.0.0001)GO TO 70
   G1=G3
   R1=R3
   GO TO 60
70 G2=G3
   R2=R3
   S2=S3
   GO TO 60
80 A1=G3
   NQ=1
   G1=1.0/(SQ-1.0)
   R1=F2(G1)
   G2=G1-5.0
   R2=F2(G2)
   S2=F4(R2,Q)
```

```
 90 G3=G2+(Q-R2)*(G2-G1)/(R2-R1)
    R3=F2(G3)
    S3=F4(R3,Q)
    IF(ABS(R3-Q).LE.0.0001)GO TO 110
    IF(NQ.GT.50)GO TO 590
    NQ=NQ+1
    IF(ABS(S2-S3).LE.0.00001)GO TO 100
    G1=G3
    R1=R3
    GO TO 90
100 G2=G3
    R2=R3
    S2=S3
    GO TO 90
110 A2=G3
    B1=A1**2*(TAN(BETA1/C1)-TAN(SB/C1))/(1.0-(A1*SQ+1.0)*EXP(-A1*SQ))
    CC1=TAN(SB/C1)+B1/A1**2
    E1=(A1*SQ+2.0)*B1/A1**3*EXP(-A1*SQ)
    B2=A2**2*(TAN(BETA2/C1)-TAN(SB/C1))/(1.0+(A2*(1.0-SQ)-1.0)*EXP(A2*
   1(1.0-SQ)))
    CC2=TAN(SB/C1)+B2/A2**2
    D2=2.*(B2/A2**3-B1/A1**3)+SQ*(CC1-CC2)+E1
    XD=1.0-SQ
    R2=F3(A2,B2,CC2,D2)
    XMLC=SQRT(1.0+R2**2)
    GO TO 120
112 I1=1
    BETA3=BETA1+SB
    S0=0.
    X0=0.
    Y0=0.
    Y21=0.0
    I2=FLOAT(N)*SQ
    IF(I2.LE.1) SQ= 0.0
    IF(I2.LE.1) BETA3=BETA1
    IF(I2.LE.1) GO TO 113
    XRNGE=SQ
    FACT=SQ
    CALL GQ(BETA1,BETA3,I1,I2,FACT,X0,Y0,S0,XRNGE,Y11,X11,Y21,RDIUS1,S
   1,C1)
```

```
      I1=I2
      X0=SQ
      Y0=Y21
      S0=S(I1)
  113 I2=N
      FACT=1.-SQ
      XRNGE=FACT
      CALL GQ(BETA3,BETA2,I1,I2,FACT,X0,Y0,S0,XRNGE,Y12,X12,Y22,RDIUS2,S
     1,C1)
      XMLC=SQRT(1.0+Y22**2)
      GO TO 120
  115 CALL GQ(BETA1,BETA2,1,N,1.0,0.0,0.0,0.0,1.0,Y1,X1,Y2,RDIUS,S,C1)
      XMLC=SQRT(1.+Y2**2)
      CHORD=XMLC/(1.-2.*YZERO*(1.-XMLC))
      FCSLMN=1.0-CHORD*2.*YZERO
      GO TO 121
  120 CHORD=XMLC/(1.0-YZERO+XMLC*(YZERO+ABS(YONE*SIN(BETA2/C1))))
      FCSLMN=1.0-CHORD*(YZERO+ABS(YONE*SIN(BETA2/C1)))
  121 IF(IFCORD.EQ.1)AXIALC=AXIALC/CHORD
      YZERO=YZERO*CHORD/FCSLMN
      YONE=YONE*CHORD/FCSLMN
      T=T*CHORD/FCSLMN
      S(1)=0.0
      XX=0.0
      XN=N
      IF(ISECN.EQ.2) GO TO 181
      AT=(YZERO-T/2.0)/(2.0*Z**3)
      CT=(T/2.0-YZERO)*3.0/(2.0*Z)
      DT=YZERO
      ET=(YONE-T/2.0)/(1.0-Z)**3-1.5*(YZERO-T/2.0)/(Z**2*(1.0-Z))
      FT=1.5*(YZERO-T/2.0)/Z**2
      HT=T/2.0
      IF(ISECN.EQ.3) GO TO 181
      DELX=1.0/(10.0*(XN-1.0))
      ASSIGN 140 TO ISEC1
      ASSIGN 210 TO ISEC2
      IF(ISECN.EQ.0)GO TO 130
      ASSIGN 150 TO ISEC1
      ASSIGN 220 TO ISEC2
  130 DO 180 J=2,N
```

```
      DO 170 JJ=1,11
      GO TO ISEC1,(140,150)
  140 PHI(JJ)=SQRT(1.0+(OA/12.0*(XX-H)**3+XK2*2.0*XX+B)**2)
      GO TO 170
  150 XD=XX-SQ
      IF(XD.GT.0.0)GO TO 160
      PHI(JJ)=SQRT(1.0+(F5(A1,B1,CC1))**2)
      GO TO 170
  160 PHI(JJ)=SQRT(1.+(F5(A2,B2,CC2))**2)
  170 XX=XX+DELX
      XX=XX-DELX
  180 S(J)=S(J-1)+(PHI(1)+PHI(11)+4.0*(PHI(2)+PHI(4)+PHI(6)+PHI(8)+PHI(1
     10))+2.0*(PHI(3)+PHI(5)+PHI(7)+PHI(9)))/(30.0*(XN-1.0))
  181 DELX=1.0/(XN-1.0)
      IF(ISECN.NE.2) GO TO 185
      T2=T/2.
      TPRIM2=T2-YZERO
      C2=2.*C1
      AFORM=(TPRIM2+RDIUS*(1.-COS((BETA1-BETA2)/C2)))/XMLC*2.
      PHIS=ACOS((1.-AFORM**2)/(1.+AFORM**2))
      RS=YZERO+XMLC/2./SIN(PHIS)
      YSS=RDIUS-RS+T2
      BFORM=(RDIUS*(1.-COS((BETA1-BETA2)/C2))-TPRIM2)/XMLC*2.
      PHIP=ACOS((1.-BFORM**2)/(1.+BFORM**2))
      PHI2=ABS((BETA1-BETA2)/C1)
  185 XM(1)=0.0
      IF(ISECN.NE.3) GO TO 186
      YMM=0.0
      XMM=0.0
      I2=SQ*FLOAT(N)
      I3=I2
      IF(I2.LE.1) I2=N+1
      DELX=SQ/FLOAT(I2-1)
      IF(I3.NE.I2) I3=1
      DELXX=(1.-SQ)/FLOAT(N-I3)
      IF(I2.EQ.(N+1)) DELX=DELXX
  186 DO 250 J=1,N
      SN=S(J)/S(N)
      IF(ISECN.EQ.2) GO TO 237
      IF(SN.GT.Z)GO TO 190
```

```
      THICK2(J)=(AT*SN**2+CT)*SN+DT
      GO TO 200
  190 SN=SN-Z
      THICK2(J)=(ET*SN+FT)*SN**2+HT
  200 IF(ISECN.EQ.3) GO TO 233
      GO TO ISEC2,(210,220)
  210 YM(J)=OA48*(XM(J)-H)**4+XK2*XM(J)**2+B*XM(J)+C
      YPRIME=OA/12.0*(XM(J)-H)**3+XK2*2.0*XM(J)+B
      GO TO 240
  220 XD=XM(J)-SQ
      IF(XD.GT.0.0)GO TO 230
      YM(J)=F3(A1,B1,CC1,E1)
      YPRIME=F5(A1,B1,CC1)
      GO TO 240
  230 YM(J)=F3(A2,B2,CC2,D2)
      YPRIME=F5(A2,B2,CC2)
      GO TO 240
  233 IF((XM(J)-SQ).GT.0.0.OR.XM(J).EQ.0.0.AND.SQ.EQ.0.0)  GO TO 235
      IF(BETA1.EQ.BETA3) GO TO 239
      BTA1=BETA1
      BTA2=BETA3
      RDIUS=RDIUS1
      Y1=Y11
      X1=X11
      GO TO 238
  235 IF(BETA2.EQ.BETA3) GO TO 239
      RDIUS=RDIUS2
      X1=X12
      Y1=Y12
      BTA1=BETA3
      BTA2=BETA2
      GO TO 238
  237 PHIX=(SN-0.5)*PHI2
      THICK2(J)=YSS*COS(PHIX)+SQRT(RS**2-YSS**2*SIN(PHIX)**2) -RDIUS
  238 YM(J)=F6(XM(J))
      YPRIME=F8(XM(J))
      IF((BTA1-BTA2).LT.0.0) YPRIME=-YPRIME
      IF((BTA1-BTA2).LT.0.0) YM(J)=F7(XM(J))
      IF(ISECN.EQ.2) GO TO 240
      IF(J.EQ.I3) DELX=DELXX
```

```
      GO TO 240
  239 YPRIME=TAN(BETA3/C1)
      IF( J.NE.1) XMM=XM(J-1)/FCSLMN-YZERO
      IF( J.NE.1) YMM=YM(J-1)/FCSLMN
      YM(J)=YPRIME*(XM(J)-XMM)+YMM
      IF(J.EQ.I3) DELX=DELXX
  240 XM(J+1)=XM(J)+DELX
      FYPR=1.0/SQRT(1.0+YPRIME**2)
      XS(IBL,J)=(XM(J)-THICK2(J)*YPRIME*FYPR+YZERO)*FCSLMN
      YS(IBL,J)=(YM(J)+THICK2(J)*FYPR)*FCSLMN
      XP(IBL,J)=(XM(J)+THICK2(J)*YPRIME*FYPR+YZERO)*FCSLMN
      YP(IBL,J)=(YM(J)-THICK2(J)*FYPR)*FCSLMN
      AM(J)=ATAN(YPRIME)*C1
      XM(J)=(XM(J)+YZERO)*FCSLMN
      YM(J)=YM(J)*FCSLMN
      THICK2(J)=THICK2(J)*FCSLMN
  250 S(J)=S(J)*FCSLMN
      YZERO=YZERO*FCSLMN
      AREA=PI/2.0*YZERO**2
      XINT=YZERO*(1.0-COS(BETA1/C1)*4.0/(3.0*PI))*AREA
      YINT=-4.0/(3.0*PI)*YZERO*AREA*SIN(BETA1/C1)
      DO 260 J=2,N
      DELA=(THICK2(J)+THICK2(J-1))*(S(J)-S(J-1))
      AREA=AREA+DELA
      XINT=XINT+DELA*(XM(J)+XM(J-1))/2.0
  260 YINT=YINT+DELA*(YM(J)+YM(J-1))/2.0
      IF(ISECN.NE.2) GO TO 261
      AREA2=PI/2.*YZERO**2
      XINT=XINT+AREA2*(XM(N)+4.*YZERO/(3.*PI)*COS(BETA2/C1))
      YINT=YINT+AREA2*(YM(N)+4.*YZERO/(3.*PI)*SIN(BETA2/C1))
      AREA=AREA+AREA2
  261 XBAR=XINT/AREA
      YBAR=YINT/AREA
      XBARB=XBAR
      YBARB=YBAR
      YBAR=YBAR+YDEL/AXIALC
      XBAR=XBAR+XDEL/AXIALC
      AX=1./99.
      DX(1)=0.
      DO 262 IK=2,100
```

```
262 DX(IK)=DX(IK-1)+AX
    YMM=0.0
    XMM=0.0
    DO 270 IK=1,100
    XAB=DX(IK)
    IF(ISECN.EQ.0) GO TO 263
    IF(ISECN.EQ.1) GO TO 264
    IF(ISECN.EQ.2) GO TO 268
    IF(ISECN.EQ.3) GO TO 266
263 Y(IK)   =(0A48*(XAB-H)**4+XAB**2*XK2+B*XAB+C)*FCSLMN
    SS1(IK,1)=0A/12.*(XAB-H)**3+XK2*2.*XAB+B
    GO TO 270
264 XD=XAB-SQ
    IF(XD.GT.0.0) GO TO 265
    Y(IK)=F3(A1,B1,CC1,E1)*FCSLMN
    SS1(IK,1)=F5(A1,B1,CC1)
    GO TO 270
265 Y(IK)=F3(A2,B2,CC2,D2)*FCSLMN
    SS1(IK,1)=F5(A2,B2,CC2)
    GO TO 270
266 IF((XAB-SQ).GT.0.0.OR.XAB.EQ.0.0.AND.SQ.EQ.0.0) GO TO 267
    IF(BETA1.EQ.BETA3) GO TO 269
    RDIUS=RDIUS1
    X1=X11
    Y1=Y11
    BTA1=BETA1
    BTA2=BETA3
    GO TO 268
267 IF(BETA2.EQ.BETA3) GO TO 269
    RDIUS=RDIUS2
    X1=X12
    Y1=Y12
    BTA1=BETA3
    BTA2=BETA2
268 Y(IK)=F6(XAB)*FCSLMN
    SS1(IK,1)=F8(XAB)
    IF((BTA1-BTA2).LT.0.0) SS1(IK,1)=-SS1(IK,1)
    IF((BTA1-BTA2).LT.0.0) Y(IK)=F7(XAB)*FCSLMN
    GO TO 270
269 SS1(IK,1)=TAN(BETA3/C1)
```

```
      IF(IK.NE.1) YMM=Y(IK-1)/FCSLMN
      IF(IK.NE.1) XMM=DX(IK-1)
      Y(IK)=(SS1(IK,1)*(XAB-XMM)+YMM)*FCSLMN
  270 SIGMA(IK)=DX(IK)*FCSLMN+YZERO
      CALL D1(SIGMA,Y     ,100,DX    ,DY    ,100,1)
      CALL D1(SIGMA,SS1(1,1),100,DX,Y,100,1)
      CALL D1(DX    ,DY    ,100,XBAR ,XAB  ,1   ,1)
      CALL D1(DX,Y,100,XBAR,XBC,1,1)
      XBAR=XBARB
      YBAR=YBARB
      IX=0.0
      IY=0.0
      IXY=0.0
      DO 275 J=2,N
      DELA=(THICK2(J)+THICK2(J-1))*(S(J)-S(J-1))
      IXD=(THICK2(J)+THICK2(J-1))**3*(S(J)-S(J-1))/12.0
      IYD=(THICK2(J)+THICK2(J-1))*(S(J)-S(J-1))**3/12.0
      COSANG=COS((AM(J)+AM(J-1))/C1)
      IXN=(IXD+IYD+(IXD-IYD)*COSANG)/2.0
      IYN=(IXD+IYD-(IXD-IYD)*COSANG)/2.0
      IXYN=0.0
      IF((AM(J)+AM(J-1)).NE.0.0)IXYN=((IXN-IYN)*COSANG-IXD+IYD)/(2.0*SIN
     1((AM(J)+AM(J-1))/C1))
      IX=IX+IXN+DELA*((YM(J)+YM(J-1))/2.0-YBAR)**2
      IY=IY+IYN+DELA*((XM(J)+XM(J-1))/2.0-XBAR)**2
  275 IXY=IXY+IXYN+DELA*(YBAR-(YM(J)+YM(J-1))/2.0)*(XBAR-(XM(J)+XM(J-1))
     1/2.0)
      ANG=ATAN(2.0*IXY/(IY-IX))
      IPX=(IX+IY)/2.0+(IX-IY)/2.0*COS(ANG)-IXY*SIN(ANG)
      IPY=(IX+IY)/2.0-(IX-IY)/2.0*COS(ANG)+IXY*SIN(ANG)
      ANG=ANG/2.0*C1
      STAGER=ATAN(YM(N)/XM(N))*C1
      XML=XM(N)
      YML=YM(N)
      CAMBER=BETA1-BETA2
      IF(IPRINT.EQ.2)GO TO 350
      LNCT=47
      IF(ISECN.EQ.1.OR.ISECN.EQ.3) LNCT=49
      WRITE(LOG2,280)CHORD,STAGER,CAMBER,AREA,XBAR,YBAR,IX,IY,IXY,ANG,IP
     1X,ANG,IPY,ANG
```

```
280 FORMAT(/,16X,100HNORMALISED RESULTS - ALL THE FOLLOWING REFER TO A
   1BLADE HAVING A MERIDIONAL CHORD PROJECTION OF UNITY,/,16X,100(1H*)
   2                                                ,//20X,11HBLADE CHORD,4X
   3,1H=,F7.4,//,20X,16HSTAGGER ANGLE  =,F7.3,//,20X,16HCAMBER ANGLE
   4 =,F7.3,//,20X,16HSECTION AREA   =,F7.5,//,20X,45HLOCATION OF CENT
   5ROID RELATIVE TO LEADING EDGE,//,30X,6HXBAR =,F8.5,/,30X,6HYBAR =,
   6F8.5,//,20X,37HSECOND MOMENTS OF AREA ABOUT CENTROID,//,30X,6HIX
   7 =,F8.5,/,30X,6HIY   =,F8.5,/,30X,6HIXY  =,F8.5,//,20X,58HANGLE OF
   8 INCLINATION OF (ONE) PRINCIPAL AXIS TO 'X' AXIS =,F7.3,//,20X,47H
   9PRINCIPAL SECOND MOMENTS OF AREA ABOUT CENTROID,//,30X,6HIPX  =,F7
   A.5,6X,3H(AT,F7.3,15H WITH 'X' AXIS),/,30X,6HIPY  =,F7.5,6X,3H(AT,F
   B7.3,15H WITH 'Y' AXIS),//)
290 FORMAT(27X,5HPOINT,8X,24HM E A N L I N E  D A T A ,13X,23HSURFACE
   1COORDINATE DATA,/,27X,6HNUMBER,5X,1HX,7X,1HY,5X,15HANGLE THICKNESS
   2,9X,2HXS,6X,2HYS,6X,2HXP,6X,2HYP,//)
    WRITE(LOG2,290)
    DO 310 J=1,N
    IF(LNCT.NE.60)GO TO 300
    WRITE(LOG2,10)
    WRITE(LOG2,290)
    LNCT=4
300 LNCT=LNCT+1
    TM=THICK2(J)*2.0
310 WRITE(LOG2,320)J,XM(J),YM(J),AM(J),TM,XS(IBL,J),YS(IBL,J),XP(IBL,J
   1),YP(IBL,J)
320 FORMAT(27X,I3,F13.5,F8.5,F7.3,F8.5,F16.5,3F8.5)
    DO 330 J=1,N
    XM(J)=XS(IBL,J)
    YM(J)=YS(IBL,J)
    AM(J)=XP(IBL,J)
330 THICK2(J)=YP(IBL,J)
    WRITE(LOG2,340)IBL
340 FORMAT(1H1,45X,33HNORMALISED PLOT OF SECTION NUMBER,I3,/,2X)
    CALL EQ(N,LOG2,XM,YM,AM,THICK2)
350 A2=AXIALC**2
    A4=A2**2
    IX=IX*A4
    IY=IY*A4
    IXY=IXY*A4
    IPX=IPX*A4
```

```
      IPY=IPY*A4
      IF(ISTAK.GT.1) GO TO 352
      XBAR=ISTAK
      IF(ISTAK.EQ.0) YBAR=0.
      IF(ISTAK.EQ.1) YBAR=YML
  352 RLE=YZERO*AXIALC
      CHORD=CHORD*AXIALC
      AREA=AREA*A2
      XC=RLE-XBAR*AXIALC-XDEL
      YC=-YBAR*AXIALC-YDEL
      XTC=(XML-XBAR)*AXIALC-XDEL
      YTC=(YML-YBAR)*AXIALC-YDEL
      IF(IPRINT.EQ.2)GO TO 390
      IF(ISECN.EQ.2) GO TO 362
      WRITE(LOG2,360)CHORD,RLE,XC,YC,AREA,IX,IY,IXY,IPX,ANG,IPY,ANG
  360 FORMAT(1H1,31X,69HDIMENSIONAL RESULTS - ALL RESULTS REFER TO A BLA
     1DE OF SPECIFIED CHORD,/,32X,69H***********************************
     2**********************************,//,20X,11HBLADE CHORD,4X,1H=,1P
     3E12.5,//,20X,10HL.E.RADIUS,5X,1H=,1PE12.5,8X,14HCENTERED AT X=,1PE
     413.5,3H Y=,1PE13.5,//,20X,16HSECTION AREA   =,1PE12.5,//,20X,37HSE
     5COND MOMENTS OF AREA ABOUT CENTROID,//,30X,6HIX   =,1PE12.5,/,30X,
     66HIY   =,1PE12.5,/,30X,6HIXY  =,1PE12.5,//,20X,47HPRINCIPAL SECOND
     7 MOMENTS OF AREA ABOUT CENTROID,//,30X,6HIPX  =,1PE12.5,5H  (AT,0P
     8F7.3,15H WITH 'X' AXIS),/,30X,6HIPY  =,1PE12.5,5H  (AT,0PF7.3,15H
     9WITH 'Y' AXIS),//)
      GO TO 364
  362 CONTINUE
      WRITE(LOG2,363) CHORD,RLE,XC,YC,XTC,YTC,AREA,IX,IY,IXY,IPX,ANG,
     1 IPY,ANG
  363 FORMAT(1H1,31X,69HDIMENSIONAL RESULTS - ALL RESULTS REFER TO A BLA
     1DE OF SPECIFIED CHORD,/,32X,69H***********************************
     2**********************************,//,20X,11HBLADE CHORD,4X,1H=,1P
     3E12.5,//,20X,9HEND RADII,6X,1H=,1PE12.5,8X,14HCENTERED AT X=,1PE13
     A.5,3H Y=,1PE13.5,/,64X,6HAND X=,1PE13.5,3H Y=,1PE13.5,/,
     4                  20X,16HSECTION AREA   =,1PE12.5,//,20X,37HSE
     5COND MOMENTS OF AREA ABOUT CENTROID,//,30X,6HIX   =,1PE12.5,/,30X,
     66HIY   =,1PE12.5,/,30X,6HIXY  =,1PE12.5,//,20X,47HPRINCIPAL SECOND
     7 MOMENTS OF AREA ABOUT CENTROID,//,30X,6HIPX  =,1PE12.5,5H  (AT,0P
     8F7.3,15H WITH 'X' AXIS),/,30X,6HIPY  =,1PE12.5,5H  (AT,0PF7.3,15H
     9WITH 'Y' AXIS),//)
```

```
364 WRITE(LOG2,370)
    WRITE(LOG2,380)
370 FORMAT(124H     PT       SUCTION------SURFACE          PRESSURE-----SUR
   1FACE          PT       SUCTION------SURFACE          PRESSURE-----SURF
   2ACE)
380 FORMAT
   1(4X,2HNO,8X,1HX,13X,1HY,13X,1HX,13X,1HY,12X,2HNO,8X,1HX13X,1HY,13X
   2,1HX,13X,1HY,//)
    LNCT=24
390 DO 420 J=1,N
    XS(IBL,J)=(XS(IBL,J)-XBAR)*AXIALC-XDEL
    YS(IBL,J)=(YS(IBL,J)-YBAR)*AXIALC-YDEL
    XP(IBL,J)=(XP(IBL,J)-XBAR)*AXIALC-XDEL
    YP(IBL,J)=(YP(IBL,J)-YBAR)*AXIALC-YDEL
    IF(IPRINT.EQ.2)GO TO 420
    IF((J/2)*2.NE.J)GO TO 420
    IF(LNCT.NE.60)GO TO 400
    LNCT=4
    WRITE(LOG2,10)
    WRITE(LOG2,370)
    WRITE(LOG2,380)
400 LNCT=LNCT+1
    JM1=J-1
    WRITE(LOG2,410)JM1,XS(IBL,JM1),YS(IBL,JM1),XP(IBL,JM1),YP(IBL,JM1)
   1,J,XS(IBL,J),YS(IBL,J),XP(IBL,J),YP(IBL,J)
410 FORMAT(3X,I3,4(2X,1PE12.5),6X,I3,4(2X,1PE12.5))
420 CONTINUE
    IF(IPRINT.EQ.2)GO TO 460
    IF(LNCT.GT.24)WRITE(LOG2,440)
440 FORMAT(1H1)
    IF(LNCT.GT.24) LNCT=2
    LNCT=LNCT+5
    IF(ISECN.EQ.2) GO TO 481
    WRITE(LOG2,450)
450 FORMAT(2X,/,48X,37HPOINTS DESCRIBING LEADING EDGE RADIUS,//,48X,9H
   1POINT NO.,6X,1HX,13X,1HY,/,2X)
460 EPS=BETA1+180.0
    IF(ISECN.EQ.2) GO TO 481
    DO 480 J=1,31
    XSEMI(IBL,J)=XC-RLE*SIN(EPS/C1)
```

```
      YSEMI(IBL,J)=YC+RLE*COS(EPS/C1)
      EPS=EPS-6.0
      IF IPRINT.EQ.2)GO TO 480
      WRITE(LOG2,470)J,XSEMI(IBL,J),YSEMI(IBL,J)
      LNCT=LNCT+1
  470 FORMAT(48X,I5,1PE17.5,1PE14.5)
  480 CONTINUE
      GO TO 499
  481 PHISS=PHIS-ABS((BETA1-BETA2)/C2)
      PHIPP=ABS((BETA1-BETA2))/C2-PHIP
      EPS=BETA1+180.0
      EPS2=BETA2+90.
      DELEP=(180.-(PHISS+PHIPP)*C1)/28.
      DO 489 J=1,31
      IF(J.NE.1) GO TO 485
      XSEMI(IBL,J)=XP(IBL,1)
      YSEMI(IBL,J)=YP(IBL,1)
      XSEMJ(IBL,J)=XS(IBL,N)
      YSEMJ(IBL,J)=YS(IBL,N)
      EPS=EPS-PHIPP*C1
      EPS2=EPS2-PHISS*C1
      GO TO 489
  485 IF(J.NE.31) GO TO 486
      XSEMI(IBL,J)=XS(IBL,1)
      YSEMI(IBL,J)=YS(IBL,1)
      YSEMJ(IBL,J)=YP(IBL,N)
      XSEMJ(IBL,J)=XP(IBL,N)
      GO TO 489
  486 XSEMI(IBL,J)=XC-RLE*SIN(EPS/C1)
      YSEMI(IBL,J)=YC+RLE*COS(EPS/C1)
      XSEMJ(IBL,J)=XTC+RLE*COS(EPS2/C1)
      YSEMJ(IBL,J)=YTC+RLE*SIN(EPS2/C1)
      EPS=EPS-DELEP
      EPS2=EPS2-DELEP
  489 CONTINUE
      IF(IPRINT.EQ.2) GO TO 499
      WRITE(LOG2,491)
  491 FORMAT(2X,/,39X,44HPOINTS DESCRIBING LEADING AND TRAILING EDGES,
     1 /,25X,12HLEADING EDGE,22X,13HTRAILING EDGE,/,2X,9HPOINT NO.,4X,
     2 8X,1HX,14X,1HY,12X,8X,1HX,14X,1HY,/,2X)
```

```
      WRITE(LOG2,492) (J,XSEMI(IBL,J),YSEMI(IBL,J),XSEMJ(IBL,J),
     1 YSEMJ(IBL,J),J=1,31)
      LNCT=LNCT+31
  492 FORMAT(6X,I2,7X,1PE17.5,1PE14.5,2X,1PE17.5,1PE14.5)
  499 SSURF=AXIALC
      SS2=BX-AXIALC*XBAR-XDEL
      SBAR=SS2+AXIALC*XBARB+XDEL
      DO 500  IK=1,100
  500 SS(IK)=SS(IK)-SBAR
      CALL D1(SS,X,100,0.,SBAR,1,1)
      CALL D1(XHERE,R(1,IBL),NSTNS,SBAR,RXBAR,1,0)
      XBARC=XBAR
      YBARC=YBAR
      XBAR =XBARB+XDEL/AXIALC
      YBAR =YBARB+YDEL/AXIALC
      SS1(1,1)=SS(1)
      S23=AXIALC/99.
      SS(1)=SS(1)+SS2
      DO 510  IK=2,100
      SS1(IK,1)=SS(IK)
  510 SS(IK)=SS(IK-1)+S23
      SIGMAO=(XAB-YBAR)/RXBAR*AXIALC
      DO 515  IK=2,100
      IF(XBAR.EQ.DX(IK)) GO TO 517
      IF(XBAR.GT.DX(IK-1).AND.XBAR.LT.DX(IK)) GO TO 518
  515 CONTINUE
      WRITE(LOG2,516)
  516 FORMAT(1H1,23H XBAR CANNOT BE LOCATED)
  517 SIGMA(IK)=SIGMAO
      KL=IK+1
      GO TO 520
  518 KL=IK
      SIGMA(IK-1)=SIGMAO
  520 SSDUM=SS(KL-1)
      SS(KL-1)=0.
      YP1=XBC
      RX1=RXBAR
      DO 530  IK=KL,100
      XSURF=SS2  +DX(IK)*SSURF +SS1(1,1)
      CALL D1(SS1(1 ,1),X,100,XSURF,XDUM,1,1)
```

```
      CALL D1(XHERE,R(1,IBL),NSTNS,XDUM ,RX2,1,0)
      SIGMA(IK)=SIGMA(IK-1)+(Y(IK)/RX2+YP1/RX1)/2.*(SS(IK)-SS(IK-1))
      YP1=Y(IK)
  530 RX1=RX2
      SS(KL-1)=SSDUM
      SSDUM=SS(KL)
      SIGDUM=SIGMA(KL)
      SIGMA(KL)=SIGMAO
      SS(KL)=0.
      RX1=RXBAR
      YP1=XBC
      KM=KL-1
      DO 535  IK=1,KM
      KJ=KL-IK
      XSURF=SS2  +DX(KJ)*SSURF  +SS1(1,1)
      CALL D1(SS1(1 ,1),X,100,XSURF,XDUM,1,1)
      CALL D1(XHERE,R(1,IBL),NSTNS,XDUM ,RX2,1,0)
      SIGMA(KJ)=SIGMA(KJ+1)-(Y(KJ)/RX2+YP1/RX1)/2.*(SS(KJ+1)-SS(KJ))
      YP1=Y(KJ)
  535 RX1=RX2
      SIGMA(KL)=SIGDUM
      SS(KL)=SSDUM
      DO 540  IK=1,100
  540 SS(IK)=SS1(IK,1)
      XBAR=XBARC
      YBAR=YBARC
      DO 545  IK=1,N
      SS1(IK,1)=SS2  +((XS    (IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF+SS(1)
  545 SS1(IK,2)=SS2  +((XP    (IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF +SS(1)
      DO 550  IK=1,31
  550 SS1(IK,3)=SS2  +((XSEMI(IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF +SS(1)
      IF(ISECN.NE.2) GO TO 560
      DO 555  IK=1,31
  555 SS1(IK,4)=SS2  +((XSEMJ(IBL,IK)+XDEL)/AXIALC+XBAR)*SSURF +SS(1)
      CALL D1(SS,X,100,SS1(1,4),SS1(1,4),31 ,1)
  560 CALL D1(SS,X,100,SS1(1,1),SS1(1,1),N  ,1)
      CALL D1(SS,X,100,SS1(1,2),SS1(1,2),N  ,1)
      CALL D1(SS,X,100,SS1(1,3),SS1(1,3),31 ,1)
      IF(ISTAK.GT.1) GO TO 570
      IF(ISTAK.EQ.1) SIGMAO=SIGMA(100)
```

```
      IF(ISTAK.EQ.0) SIGMAO=SIGMA(1)
      DO 565  IK=1,100
  565 SIGMA(IK)=SIGMA(IK)-SIGMAO
  570 DO 575  IK=1,100
      DX(IK)=(DX(IK)-XBAR)*AXIALC-XDEL
  575 DY(IK)=(DY(IK)-YBAR)*AXIALC-YDEL
      DO 585  MK=1,4
      IF(ISECN.NE.2.AND.MK.EQ.4) GO TO 585
      IF(MK.EQ.4.OR.MK.EQ.3) NNN=31
      IF(MK.EQ.1.OR.MK.EQ.2) NNN=N
      DO 580  IK=1,NNN
      IF(MK.EQ.1) YP1=YS    (IBL,IK)
      IF(MK.EQ.2) YP1=YP    (IBL,IK)
      IF(MK.EQ.3) YP1=YSEMI(IBL,IK)
      IF(MK.EQ.4) YP1=YSEMJ(IBL,IK)
      IF(MK.EQ.1) RX1=XS    (IBL,IK)
      IF(MK.EQ.2) RX1=XP    (IBL,IK)
      IF(MK.EQ.3) RX1=XSEMI(IBL,IK)
      IF(MK.EQ.4) RX1=XSEMJ(IBL,IK)
      CALL D1(DX,DY,100,RX1,RXBAR,1,1)
      DELLY=YP1-RXBAR
      CALL D1(XHERE,R(1,IBL),NSTNS,SS1(IK,MK),RAB,1,0)
      DELSIG=DELLY/RAB
      CALL D1(DX,SIGMA,100,RX1,XAB,1,1)
  580 SS1(IK,MK)=XAB+DELSIG
  585 CONTINUE
      RETURN
  590 WRITE(LOG2,600)
  600 FORMAT(1H1,10X,54HITERATIVE SOLUTION FOR CONSTANT FAILS - CASE ABA
     1NDONED)
      STOP
      END
```

```
      SUBROUTINE CQ(XDATA,YDATA,NDATA,XIN,YOUT,YPRIME,NXY,NWOT)
C THIS SPLINE ROUTINE DETERMINES Y AND/OR YPRIME  LINEAR EXTRAPOLATIONS
C XDATA AND XIN MUST BE IN ASCENDING ORDER  E1 AND E2 ARE D2YDX2 LAST /
C D2YDX2 LAST-BUT-ONE AT ENDS OF SPECIFIED REGION OF BEAM
      REAL M
      DIMENSION A(65),B(65),D(65),M(65),XDATA(1),YDATA(1),XIN(1),YOUT(1)
     1,YPRIME(1)
      IF(NDATA-2) 100,1,9
    1 IF(NWOT-1) 3,5,3
    3 DO 4 I=1,NXY
    4 YOUT(I)=((YDATA(2)-YDATA(1))/(XDATA(2)-XDATA(1)))*(XIN(I)-XDATA(1)
     1 )+YDATA(1)
    5 IF(NWOT) 100,100,6
    6 DO 7 I=1,NXY
    7 YPRIME(I)=(YDATA(2)-YDATA(1))/(XDATA(2)-XDATA(1))
      GO TO 100
    9 CONTINUE
      E1=1.0
      E2=1.0
      A(1)=1.0
      B(1)=-E1
      D(1)=0.0
      N=NDATA-1
      DO 10 I=2,N
      A(I)=(XDATA(I+1)-XDATA(I-1))/3.0-(XDATA(I)-XDATA(I-1))*B(I-1)/(6.0
     1*A(I-1))
      B(I)=(XDATA(I+1)-XDATA(I))/6.0
10    D(I)=(YDATA(I+1)-YDATA(I))/(XDATA(I+1)-XDATA(I))-(YDATA(I)-YDATA(I
     1-1))/(XDATA(I)-XDATA(I-1))-(XDATA(I)-XDATA(I-1))*D(I-1)/6.0/A(I-1)
      A(NDATA)=-E2
      B(NDATA)=1.0
      D(NDATA)=0.0
      M(NDATA)=A(NDATA)*D(N)/(A(NDATA)*B(N)-A(N)*B(NDATA))
      DO 20 II=2,NDATA
      I=NDATA+1-II
20    M(I)=(D(I)-B(I)*M(I+1))/A(I)
      J=1
      I=1
30    IF(XIN(I)-XDATA(1))95,95,35
35    IF(XIN(I)-XDATA(J+1))60,60,40
```

```
40     IF(J+1-NDATA)50,60,60
50     J=J+1
       GO TO 35
60     IF(XIN(I)-XDATA(NDATA))65,98,98
65     DX=XDATA(J+1)-XDATA(J)
       IF(NWOT-1)70,80,70
70     YOUT(I)=M(J)/(6.0*DX)*(XDATA(J+1)-XIN(I))**3+M(J+1)/(6.0*DX)*(XIN(
      1I)-XDATA(J))**3+(XDATA(J+1)-XIN(I))*(YDATA(J)/DX-M(J)/6.0*DX)+(XIN
      2(I)-XDATA(J))*(YDATA(J+1)/DX-M(J+1)/6.0*DX)
       IF(NWOT)80,90,80
80     YPRIME(I)=(-M(J)*(XDATA(J+1)-XIN(I))**2/2.0+M(J+1)*(XIN(I)-XDATA(J
      1))**2/2.0+YDATA(J+1)-YDATA(J))/DX-(M(J+1)-M(J))/6.0*DX
90     I=I+1
       IF(I-NXY)30,30,100
95     YDASH=(YDATA(2)-YDATA(1))/(XDATA(2)-XDATA(1))-(M(1)/3.0+M(2)/6.0)*
      1(XDATA(2)-XDATA(1))
       IF(NWOT-1)96,97,96
96     YOUT(I)=YDATA(1)-YDASH*(XDATA(1)-XIN(I))
       IF(NWOT)97,90,97
97     YPRIME(I)=YDASH
       GO TO 90
98     YDASH=(YDATA(NDATA)-YDATA(N))/(XDATA(NDATA)-XDATA(N))+(M(NDATA)/3.
      10+M(N)/6.0)*(XDATA(NDATA)-XDATA(N))
       IF(NWOT-1)99,97,99
99     YOUT(I)=YDATA(NDATA)+YDASH*(XIN(I)-XDATA(NDATA))
       IF(NWOT)97,90,97
100    RETURN
       END
```

```
      SUBROUTINE D1(XDATA,YDATA,NDATA,XIN,YOUT,NXY,NTYPE)
      REAL M
      DIMENSION M(15),A(15),B(15),D(15),XDATA(1),YDATA(1),XIN(1),YOUT(1)
      IF(NDATA-1)10,10,30
   10 DO 20 I=1,NXY
   20 YOUT(I)=YDATA(1)
      RETURN
   30 IF(NDATA-2)50,50,40
   40 IF(NTYPE)180,180,50
   50 J=1
      I=1
   60 IF(XIN(I)-XDATA(2))130,130,70
   70 IF(XIN(I)-XDATA(NDATA-1))80,140,140
   80 IF(XIN(I)-XDATA(J))100,120,90
   90 IF(XIN(I)-XDATA(J+1))120,120,100
  100 J=J+1
      IF(J-NDATA)80,110,110
  110 J=1
      GO TO 80
  120 YOUT(I)=YDATA(J)+(YDATA(J+1)-YDATA(J))/(XDATA(J+1)-XDATA(J))*(XIN(
     1I)-XDATA(J))
      GO TO 150
  130 YOUT(I)=YDATA(1)+(YDATA(2)-YDATA(1))/(XDATA(2)-XDATA(1))*(XIN(I)-X
     1DATA(1))
      GO TO 150
  140 YOUT(I)=YDATA(NDATA-1)+(YDATA(NDATA)-YDATA(NDATA-1))/(XDATA(NDATA)
     1-XDATA(NDATA-1))*(XIN(I)-XDATA(NDATA-1))
  150 IF(I-NXY)160,170,170
  160 I=I+1
      GO TO 60
  170 RETURN
  180 A(1)=1.0
      B(1)=0.0
      D(1)=0.0
      N=NDATA-1
      DO 190 I=2,N
      A(I)=(XDATA(I+1)-XDATA(I-1))/3.0-(XDATA(I)-XDATA(I-1))*B(I-1)/(6.0
     1*A(I-1))
      B(I)=(XDATA(I+1)-XDATA(I))/6.0
  190 D(I)=(YDATA(I+1)-YDATA(I))/(XDATA(I+1)-XDATA(I))-(YDATA(I)-YDATA(I
```

```
   1-1))/(XDATA(I)-XDATA(I-1))-(XDATA(I)-XDATA(I-1))*D(I-1)/6.0/A(I-1)
    M(NDATA)=0.0
    DO 200 II=2,N
    I=NDATA+1-II
200 M(I)=(D(I)-B(I)*M(I+1))/A(I)
    M(1)=0.0
    J=1
    I=1
210 IF(XIN(I)-XDATA(1))230,260,220
220 IF(XIN(I)-XDATA(NDATA))280,270,240
230 JP=1
    KP=2
    GO TO 250
240 JP=NDATA
    KP=NDATA-1
250 YPRIME=(YDATA(KP)-YDATA(JP))/(XDATA(KP)-XDATA(JP))-M(KP)/6.0*(XDAT
   1A(KP)-XDATA(JP))
    YOUT(I)=YDATA(JP)+(XIN(I)-XDATA(JP))*YPRIME
    GO TO 350
260 YOUT(I)=YDATA(1)
    GO TO 350
270 YOUT(I)=YDATA(NDATA)
    GO TO 350
280 IF(XIN(I)-XDATA(J))300,320,290
290 IF(XIN(I)-XDATA(J+1))340,330,300
300 J=J+1
    IF(J-NDATA)280,310,310
310 J=1
    GO TO 280
320 YOUT(I)=YDATA(J)
    GO TO 350
330 YOUT(I)=YDATA(J+1)
    GO TO 350
340 DX=XDATA(J+1)-XDATA(J)
    YOUT(I)=M(J)/(6.0*DX)*(XDATA(J+1)-XIN(I))**3+M(J+1)/(6.0*DX)*(XIN(
   1I)-XDATA(J))**3+(XDATA(J+1)-XIN(I))*(YDATA(J)/DX-M(J)/6.0*DX)+(XIN
   2(I)-XDATA(J))*(YDATA(J+1)/DX-M(J+1)/6.0*DX)
350 IF(I-NXY)360,370,370
360 I=I+1
    GO TO 210
370 RETURN
    END
```

```
      SUBROUTINE EQ(IX,LOG1,X1,Y1,X2,Y2)
      REAL LINE
      DIMENSION X1(1),Y1(1),X2(1),Y2(1),LINE(121),XNUM(13)
      DATA SYMBOL/1H*/,DASH/1H-/,CROSS/1H+/,BLANK/1H /,XI/1HI/
      YMIN=Y1(1)
      XMIN=X1(1)
      YMAX=YMIN
      XMAX=XMIN
      DO 10 I=1,IX
      IF(Y2(I).LT.YMIN)YMIN=Y2(I)
      IF(Y2(I).GT.YMAX)YMAX=Y2(I)
      IF(X2(I).LT.XMIN)XMIN=X2(I)
      IF(X2(I).GT.XMAX)XMAX=X2(I)
      IF(Y1(I).GT.YMAX)YMAX=Y1(I)
      IF(X1(I).GT.XMAX)XMAX=X1(I)
   10 CONTINUE
      IF(XMAX.EQ.XMIN.OR.YMIN.EQ.YMAX)GO TO 170
      YH=YMAX+(YMAX-YMIN)/25.0
      YL=YMIN-(YMAX-YMIN)/25.0
      XH=XMAX+(XMAX-XMIN)/38.3333
      XL=XMIN-(XMAX-XMIN)/38.3333
      IF((YH-YL)/(XH-XL).GT.0.75)XH=1.3333*(YH-YL)+XL
      IF((YH-YL)/(XH-XL).LT.0.75)YH=0.75*(XH-XL)+YL
      XMAX=(XMIN+XMAX-XH+XL)/2.0
      XH=XH-XL+XMAX
      XL=XMAX
      XMAX=(YMIN+YMAX-YH+YL)/2.0
      YH=YH-YL+XMAX
      YL=XMAX
      XMAX=ABS(XH)
      XMIN=ABS(XL)
      YMIN=ABS(YL)
      YMAX=ABS(YH)
      IF(XMIN.GT.XMAX)XMAX=XMIN
      IF(YMIN.GT.YMAX)YMAX=YMIN
      XMAX=ALOG10(XMAX)
      YMAX=ALOG10(YMAX)
      IF(XMAX.LT.0.0)XMAX=XMAX-1.0
      IF(YMAX.LT.0.0)YMAX=YMAX-1.0
      MX=-XMAX
```

```
      MY=-YMAX
      WRITE(LOG1,20)MX,MY
   20 FORMAT(20X,46HSCALES - 'X' IS SHOWN TIMES 10 TO THE POWER OF,I3,40
     1H    'Y' IS SHOWN TIMES 10 TO THE POWER OF,I3,/)
      YINC=(YH-YL)/54.0
      YINC2=YINC/2.0
      XRANGE=XH-XL
      DO 140 KLINE=1,55
      IF(KLINE.EQ.1.OR.KLINE.EQ.55)GO TO 50
      DO 30 L=2,120
   30 LINE(L)=BLANK
      IF(KLINE.EQ.7.OR.KLINE.EQ.13.OR.KLINE.EQ.19.OR.KLINE.EQ.25.OR.KLIN
     1E.EQ.31.OR.KLINE.EQ.37.OR.KLINE.EQ.43.OR.KLINE.EQ.49)GO TO 40
      LINE(1)=XI
      LINE(121)=XI
      GO TO 80
   40 LINE(1)=DASH
      LINE(121)=DASH
      GO TO 80
   50 DO 60 L=2,120
   60 LINE(L)=DASH
      LINE(1)=CROSS
      LINE(121)=CROSS
      DO 70 L=11,111,10
   70 LINE(L)=XI
      GO TO 120
   80 DO 105 I=1,IX
      IF(Y 2(I).GT.YH+YINC2.OR.Y 2(I).LE.YH-YINC2)GO TO 90
      L=(X 2(I)-XL)/XRANGE*120.0+1.5
      LINE(L)=SYMBOL
   90 IF(Y 1(I).GT.YH+YINC2.OR.Y 1(I).LE.YH-YINC2)GO TO 100
      L=(X 1(I)-XL)/XRANGE*120.0+1.5
      LINE(L)=SYMBOL
  100 CONTINUE
      IF(KLINE.EQ.1.OR.KLINE.EQ.7.OR.KLINE.EQ.13.OR.KLINE.EQ.19.OR.KLINE
     1.EQ.25.OR.KLINE.EQ.31.OR.KLINE.EQ.37.OR.KLINE.EQ.43.OR.KLINE.EQ.49
     2.OR.KLINE.EQ.55)GO TO 120
      WRITE(LOG1,110)LINE
  110 FORMAT(8X,121A1)
      GO TO 140
```

```
120 YNUM=YH*10.0**MY
    WRITE(LOG1,130)YNUM,LINE
130 FORMAT(1X,F6.3,1X,121A1)
140 YH=YH-YINC
    XNUM(1)=XL*10.0**MX
    XINC=((XH-XL)/12.0)*10.0**MX
    DO 150 I=2,13
150 XNUM(I)=XNUM(I-1)+XINC
    WRITE(LOG1,160)XNUM
160 FORMAT(6X,12(F6.3,4X),F6.3)
    RETURN
170 WRITE(LOG1,180)
180 FORMAT(//,35X,54HNO PLOT HAS BEEN MADE BECAUSE 'X' OR 'Y' RANGE IS
   1 ZERO)
    RETURN
    END
```

```
      SUBROUTINE FQ(ISTAK,PLTSZE,ITRIG,TITLE,IKDUM)
      DIMENSION TITLE(8)
      PLTTIT=PLTSZE*.1
      IF(ISTAK.LT.2) GO TO 10
      BAL=.[illegible]*PLTSZE
      XLEN1=.3*PLTSZE
      XLEN2=XLEN1
      YLEN1=.25*PLTSZE
      YLEN2=-1.*YLEN1
      XBACK1=-3.8
      XBACK2=-12.4
      GO TO 30
   10 IF(ISTAK.EQ.0) GO TO 20
      XLEN1=.70*PLTSZE
      XLEN2=.15*PLTSZE
      XBACK1=-3.8-.20*PLTSZE
      XBACK2=-12.4-.20*PLTSZE
      IF(IKDUM.EQ.1) GO TO 23
      GO TO 24
   20 CONTINUE
      XLEN1=.15*PLTSZE
      XLEN2=.70*PLTSZE
      XBACK1=-3.8+.20*PLTSZE
      XBACK2=-12.4+.20*PLTSZE
      IF(IKDUM.EQ.1) GO TO 24
   23 BAL=.25*PLTSZE
      YLEN1=.50*PLTSZE
      YLEN2=       -.15*PLTSZE
      GO TO 30
   24 BAL=.50*PLTSZE
      YLEN1=.15*PLTSZE
      YLEN2=       -.50*PLTSZE
   30 CONTINUE
      YBACK1=-(.35+BAL)
      YBACK2=YBACK1-.03*PLTSZE-.35
      IF(ITRIG.EQ.2)  GO TO 32
      CALL PLOT(0.0,0.0,-3)
      CALL PLOT(7.0   ,PLTTIT,-3)
      CALL PLOT(0.0   ,BAL    , 3)
      CALL PLOT(XLEN1,BAL    ,-2)
```

```
   32 PTSIZE=1.5*PLTSZE
      IF(ITRIG.EQ.2)CALL PLOT(PTSIZE,0.0,-3)
      IF(ITRIG.EQ.2)CALL PLOT(XLEN1,0.0,-2)
      CALL PLOT(XLEN2,0.0    , 2)
      CALL PLOT(0.0 ,YLEN1 , 3)
      CALL PLOT(0.0 ,YLEN2 , 2)
      IF(ITRIG.EQ.2) GO TO 40
      CALL SYMBOL(XBACK1,YBACK1,0.35,22HSTREAMSURFACE SECTIONS,0.0,22)
      GO TO 50
   40 XBACK1=XBACK1+0.5
      CALL SYMBOL(XBACK1,YBACK1,0.35,18HCARTESIAN SECTIONS, 0.0,18)
   50 CALL SYMBOL(XBACK2,YBACK2,0.35,TITLE,0.0,72)
      RETURN
      END
```

```
      SUBROUTINE GQ(BETA1,BETA2,I1,I2,FACT,X0,Y0,S0,XR,Y1,X1,Y2,RDIUS,S,
     1 C1)
      DIMENSION S( 80)
      DELX=XR/FLOAT(I2-I1)
      XX=X0
      I3=I1+1
      IF(BETA1.EQ.BETA2) GO TO 20
      Y1=-(TAN(BETA1/C1)/COS(BETA2/C1)**2+TAN(BETA2/C1)/COS(BETA1/C1)/
     1 COS(BETA2/C1))/(TAN(BETA1/C1)**2-TAN(BETA2/C1)**2)
      X1=-Y1*TAN(BETA1/C1)
      Y2=(Y1*(TAN(BETA2/C1)-TAN(BETA1/C1))-1.)/TAN(BETA2/C1)
      RDIUS=ABS((Y2**2+1.)/COS(BETA2/C1)/2./(Y2-TAN(BETA2/C1)))
      Y2=Y2*FACT+Y0
      Y1=Y1*FACT+Y0
      X1=X1*FACT+X0
      RDIUS=RDIUS*FACT
      DO 10 J=I3,I2
      XX=XX+DELX
      PHI1=ATAN(-1./SQRT(RDIUS**2-(XX-X1)**2)*(XX-X1))
      IF((BETA1-BETA2).LT.0.0)  PHI1=-PHI1
      PHI2=ABS(BETA1/C1-PHI1)
   10 S(J)=RDIUS*PHI2+S0
      RETURN
   20 AM=TAN(BETA1/C1)
      DO 30 J=I3,I2
      XX=XX+DELX
   30 S(J)=(XX-X0)*SQRT(AM*AM+1.0)+S0
      Y2=AM*(XX-X0)+Y0
      RETURN
      END
```

4. PROGRAM LOGIC

The analysis which has been described in this report is performed primarily in the main program and Subroutine BQ, while the other subroutine performs specific tasks supportive of the desired objectives. Subroutine BQ concerns the details of defining and describing the blade on the streamsurface; the main program utilizes this information to stack the blade and obtain the manufacturing section description. Subroutine CQ is used to find slopes of various "spline-curves" at particular points. D1 is the curve-fitting routine, EQ produces a plot in the printed portion of the output, and FQ is used to draw streamsurface and/or manufacturing section plot axes if IFPLOT = 1, 2 or 3. Subroutine GQ is used to compute the center coordinate, the radius of curvature, and the arc length for the circular-arc and multiple-circular-arc camber lines.

A description of the calculation procedure employed in the main program and in Subroutine BQ is described below. The steps of this procedure are keyed to their location in the program through the associated deck serialization, which appears parenthetically.

1. The input data is read and printed. (A1190-A2160)

2. If precision plotting is specified, the plot is initialized and if IFPLOT = 1 or 3, the axes for the superimposed streamsurface plots are produced. (A2170-A2200)

3. A loop performed for each streamsurface section is commenced. This loop creates the blade on the streamsurface. (A2210)

4. The axial locations of the intersections of a particular streamsurface with all computing stations are determined, the interval between the first and last points is subdivided into 99 intervals, and the axial coordinates of the 100 resulting locations obtained. (A2220-A2290)

5. The slope of the streamsurface at each of the 100 locations obtained in 4. above is derived. (A2300)

6. The slope of the computing stations at each of the streamsurface computing station intersection points is derived. (A2310)

7. Using Equation (74), the streamsurface length (in the meridional projection) is obtained over the 99 intervals of 4., providing an x-m table for the streamsurface. (A2320-A2340)

8. The parameters defining the streamsurface blade section are interpolated (or extrapolated) from the input tables. If NSPEC = 1, they are taken to be radially uniform. If NSPEC = 2,

linear interpolation is employed. If NSPEC > 2, spline-curve interpolation is used. (A2350-A2500)

9. The design of the streamsurface section is initiated. (A2510-A2540)

10. If IPRINT = 0 or 1, the parameters defining the streamsurface blade section are printed. (B1230-B1410)

11. If ISECN = 0, the coefficients of the quartic camber line are computed using Equations (6), (7), (8), (9) and (10). The chord length corresponding to a meridional camber line chord of unity is determined. (B1450-B1510)

12. If ISECN = 1, the coefficients for the two segments of the exponential camber line are computed using Equations (17), (18), (19), (20), (21), (22), (23) and (24). Equations (18) and (24) require iterative solution, and up to 50 attempts to satisfy the equations are permitted. The equations are taken to be satisfied when the parameter P or Q, as appropriate, is given to within 0.0001 of its specified value. (Should the iterative procedure fail, a diagnostic is printed and the job is terminated. This will not normally occur.) The chord length corresponding to a meridional camber line chord of unity is determined. (B1530-B2050)

13. If ISECN = 3, the constants of the equations for the two segments of the multiple-circular-arc camber line are determined from Equations (38), (36), (35), and (34) respectively, in Subroutine GQ. These constants are scaled and the arc center offset, if required, and the arc length of each segment determined cumulatively. The chord length corresponding to a meridional camber line chord of unity is determined. (B2070-B2300)

NOTE: Each segment is described by a proportion of the NPOINT camber line points based on its proportion of the meridionally projected chord length. If this number of points for the leading segment is 0 or 1, this segment is abandoned, and one circular arc is produced for the entire camber line.

14. If ISECN = 2, the constants of the equation for the circular-arc camber line and the camber line arc length are computed as for ISECN = 3. The chord length corresponding to a meridional chord of unity, that corresponding to an overall blade chord of unity, and an associated scale factor (described in 15.) are determined for the double-circular-arc blade. (B2320-B2350)

15. For ISECN = 0, 1 or 3, the chord length corresponding to an overall blade chord of unity as well as a scaling factor which relates the ratio of dimensions for an overall meridional chord of unity to dimensions for a camber line meridional

chord of unity are determined. (B2370-B2380)

16. If IFCORD = 1, the specified chord is divided by the chord corresponding to a unity meridional chord, giving the desired meridional chord. The three blade thickness descriptors are scaled so that they apply to a blade having a camber line meridional chord of unity. (B2390-B2420)

17. The coefficients of the two thickness equations of the standard thickness distribution are computed using Equations (42), (43), (44), (47), (48) and (49). (B2470-B2520)

18. The length of the section camber line for ISECN = 0 or 1 is determined by numerical integration. The meridional chord (of unity) is divided into (NPOINT-1) uniform intervals, where NPOINT is the number of points specified in the input to define each blade surface. The integration for the curve length between each adjacent pair of points is obtained using Simpson's Rule, the interval being subdivided into 10 equal intervals. If the polynomial camber line is specified, the gradient of the camber line is given by Equation (4). If the exponential camber line is specified, the gradient of the camber line is given by Equation (15), different coefficients applying forward and rearward of the inflection point. These data enable a location on the camber line to be expressed as a fraction of camber line length. (B2540-B2730)

19. At each of the NPOINT points, equispaced on the meridional chord, the section half-thickness is computed from Equations (41), (46) or (67), and the coordinate and slope of the camber line are computed, from either Equations (5) and (4) (polynomial), (16) and (15) (exponential), or (26) and the derivative of (26) solved for $(x-x_o)$, choosing the appropriate branch of the square root involved, for the circular-arc and multiple-circular-arc camber lines. (B2970-B3470)

20. The coordinates of NPOINT points on each blade surface are determined by combining the data derived in 19. The scaling factor derived in 14. or 15. is applied so that the blade coordinates correspond to an overall blade meridional chord of unity. (B3480-B3520)

21. The slope of the camber line is expressed in degrees. The camber line coordinates, lengths, and the section half-thickness are scaled by the factor derived in 14. or 15. (B3530-B3570)

22. The section area and the location of the centroid are determined using Equations (81), (82) and (83). (B3580-B3730)

23. The camber line is redefined in terms of 100 points to assure sufficient points for accurate linear interpolations in the determination of ε, needed for the eventual trans-

formation onto manufacturing sections. (B3780-B4240)

24. The scaled camber line is interpolated to yield its description over 99 equal axial intervals. (B4250-B4260)

25. The camber line y-coordinate and slope at the axial location of the centroid or centroid-offset are determined by linear interpolation. (B4270-B4280)

26. The product of inertia and second moments of area of the section about the centroid are determined using Equations (84), (85), (86), (87), (88), (89), (90) and (91). (B4310-B4470)

27. The orientation of the principal axes and the principal second moments of area of the section about the centroid are determined using Equations (92), (93) and (94). (B4480-B4520)

28. If IPRINT = 0 or 1, details of the normalized blade section (meridional chord unity) are printed. (B4570-B4850)

29. If IPRINT = 0 or 1, a line-printer plot of the section is made. (B4870-B4940)

30. Section properties determined in 22., 26., and 27. are scaled according to the specified section chord to produce "dimensional" results. (B4950-B5120)

31. If IPRINT = 0 or 1, section properties are printed. (B5150-B5420)

32. The coordinates of the NPOINT points on the blade surfaces are scaled according to the specified chord, and the origin is shifted to the stacking axis. The stacking axis is offset from the centroid of the section by the specified distances. If IPRINT = 0 or 1, the coordinates are printed. (B5510-B5670)

33. The coordinates of 31 points describing the blade edge(s) are determined. For the standard thickness distribution, it is assumed that the wedge angle is zero, so that the radius extends over a complete semicircle, hence the points are distributed at 6° intervals. For the double-circular-arc blade, the 2nd and 30th points of the edges are determined at the exact location of the tangency between the particular blade surface and the edge radius, resulting in an angular interval distribution uniform between points 2 and 30, with irregular first and last intervals. (B5740-B6220)

34. The origin of the m-coordinate system is shifted to the section centroid or centroid-offset as provided by the input data. (B6250-B6290)

35. The m-length corresponding to each of the 100 points describing the camber line is determined. (B6360-B6410)

36. The reference ε_0 of Equation (77) is determined. (B6420)

37. The integration of Equation (78) is performed toward the ends of the blade section from the centroid or centroid-offset, giving the ε coordinate for the camber line. (B6430-B6840)

38. The m-coordinate of each point of the blade surface is determined. (B6870-B6980)

39. The ε coordinate system is shifted to the leading or trailing edge if the blade is stacked there. (B7000-B7030)

40. The ε corresponding to each point on the section surface is determined from the ε of the camber line at that axial location and $\Delta\varepsilon$ calculated from the displacement from the camber line and the streamsurface radius. (B7070-B7260)

41. The location of the stacking axis is given (in the input data) by specifying its axial coordinate. Linear interpolation yields the corresponding streamsurface coordinate from the x-m table created in 7. (A2550)

42. The origin of the m-coordinate shifted in 34. is again shifted, to the stacking axis (determined in 41.). (A2560-A2580)

43. The origin of the table of axial coordinates of the streamsurface-computing station intersection points (obtained in 4.) is shifted to the stacking axis. (A2590-A2600)

44. If IFPLOT = 1 or 3, the streamsurface blade section plot is produced. (A2620-A2850)

45. A trigger is set if the calculation of quantities for aerodynamic analysis of the blade is specified at any computing station. (A2860-A2890)

46. If the calculations for aerodynamic analysis are specified, the angular location of the camber line with respect to the stack axis, the slope of the camber line on the streamsurface, and the Cartesian coordinates of the camber line at the streamsurface-computing station intersections are determined and stored. (A2910-A2960)

47. The axial coordinate of each of the NPOINT points specifying the streamsurface blade section suction surface is obtained by linear interpolation from the x-m table produced in 42. (A2970-A2990)

48. The streamsurface radius at each axial location derived in 47. is obtained by spline-curve interpolation from the table created in 43. (A3000)

49. Cartesian coordinates for each point on the streamsurface section suction surface are obtained using the 'ε's computed in 40. and Equation (79). (A3010-A3060)

50. Steps 47., 48., and 49. are repeated for the pressure surface. (A3070-A3160)

51. Steps 47., 48., and 49. are repeated for the points describing the leading edge. (A3170-A3260)

52. Steps 47., 48., and 49. are repeated for the points describing the trailing edge if ISECN = 2. (A3280-A3370)

53. If IPRINT = 0 or 1, the Cartesian coordinates of each point describing the streamsurface blade section are printed. (A3390-A3910)

54. The loop initiated in 3. for each streamsurface is terminated. Upon completion of this loop, the Cartesian coordinates of all streamsurface sections have now been stored for interpolation on the specified manufacturing planes. (A3920)

55. Unless IPRINT = 1, the volume of the blade is calculated, using Equation (106), and printed. (A3950-A4130)

56. If the calculations for aerodynamic analysis are specified, the program prints the appropriate heading. If not, the program moves to step 62. (A4160-A4180)

57. In the original x-r coordinate system, the axial coordinate of the streamsurfaces-computing station intersections and the computing station slope, are determined for each station at which the aerodynamic analysis quantities were specified. (A4260-A4270)

58. The blade blockage of Equation (107) is obtained at each of these points. (A4280-A4400)

59. The blade lean angle of Equation (108) is obtained at each of these points. (A4510)

60. The mean section angle of Equation (109) is obtained at each of these points. (A4530-A4540)

61. The quantities required for aerodynamic analysis are printed, and produced on cards if IPUNCH = 1. (A4550-A4570)

62. If IFPLOT = 2 or 3, the axes are drawn and titled for the superimposed plot of all the manufacturing sections. (A4620-A4630)

63. If no output relating to manufacturing sections is specified by either IFPLOT or IPRINT, the remainder of the program is bypassed. Alternatively, if printed details of the manufacturing sections are specified, a heading is printed. (A4640-A4700)

64. The location of each of the manufacturing planes is determined. (A4710-A4760)

65. The (Cartesian) coordinates of each of NPOINT points on the blade surface are obtained by spline-curve interpolation at each of the manufacturing sections. (A4770-A4860)

66. The (Cartesian) coordinates of each of 31 points describing the blade edge(s) are obtained by spline-curve interpolation at each of the manufacturing sections. (A4870-A4990)

67. A loop that is performed for each manufacturing section is initiated. This loop contains the determination of section properties and the output of results for the section. (A5000)

68. The section area and location of the centroid are determined using Equations (98), (99) and (100). (A5010-A5250)

69. The torsional constant is determined using Equations (104) and (105). (A5260-A5420)

70. The second moments of area and product of inertia for the manufacturing section about its centroid are determined using Equations (101), (102), (103), (86), (87), (88), (89), (90) and (91). (A5430-A5650)

71. From the second moments of area and product of inertia, the orientation of the principal axes and hence principal moments of area are determined, using Equations (92), (93) and (94). (A5660-A5690)

72. If IPRINT = 0 or 2, section properties and coordinates are printed. (A5720-A6260)

73. If IFPLOT = 2 or 3, a plot of the manufacturing section is produced. (A6310-A6530)

74. If IFPLOT = 4, an individual plot of the manufacturing sections is made. The axes are rotated clockwise until the chord line is horizontal. The angle of rotation is indicated as the stagger angle. (A6550-A7070)

75. The loop initiated in Step 67. for each manufacturing section is terminated. (A7080)

76. If precision plots have been made, the plotting is terminated. (A7090)

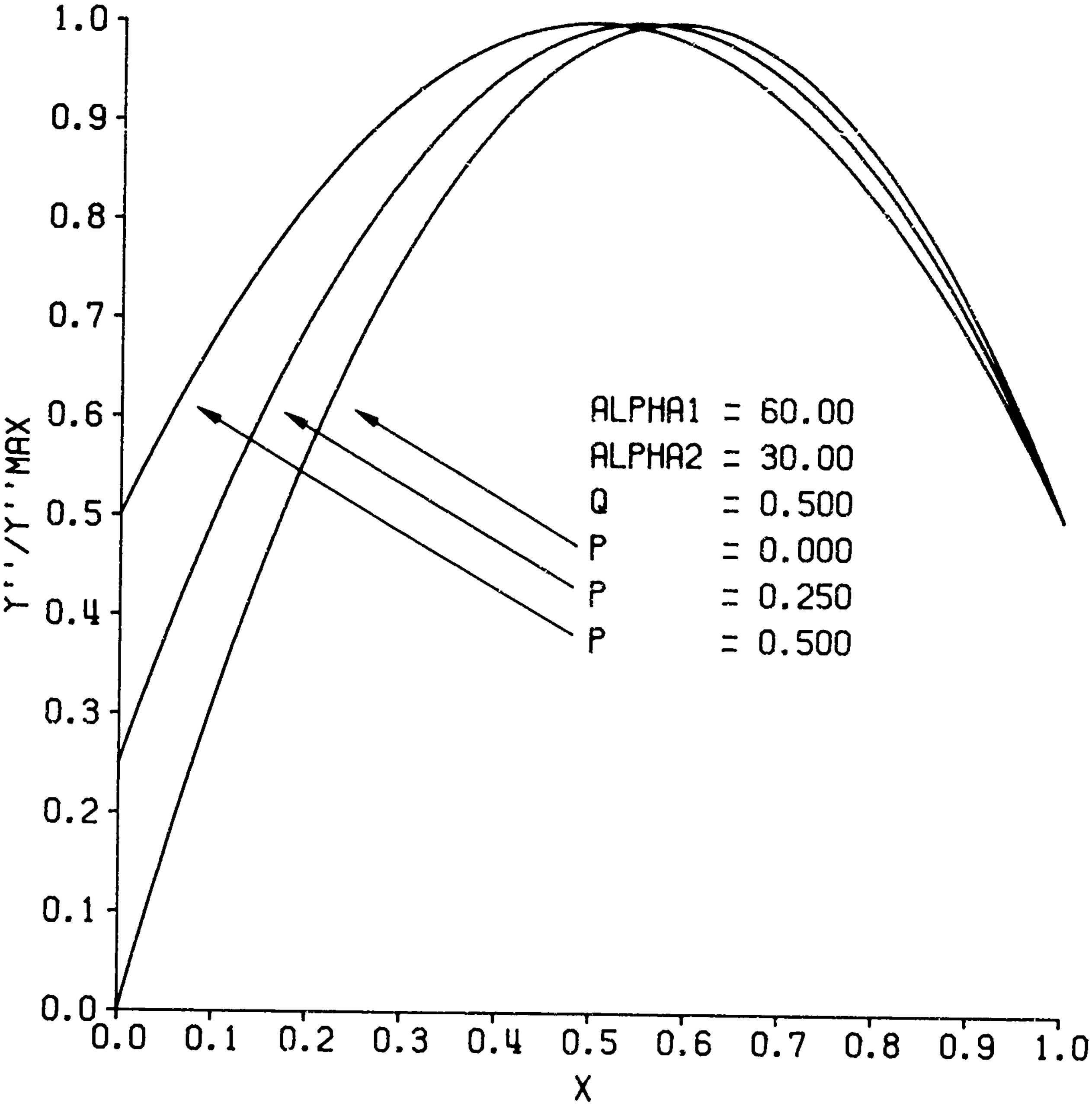


Figure 1 Variation of Normalized Second Derivative of Polynomial Camber Line with Parameter 'P'

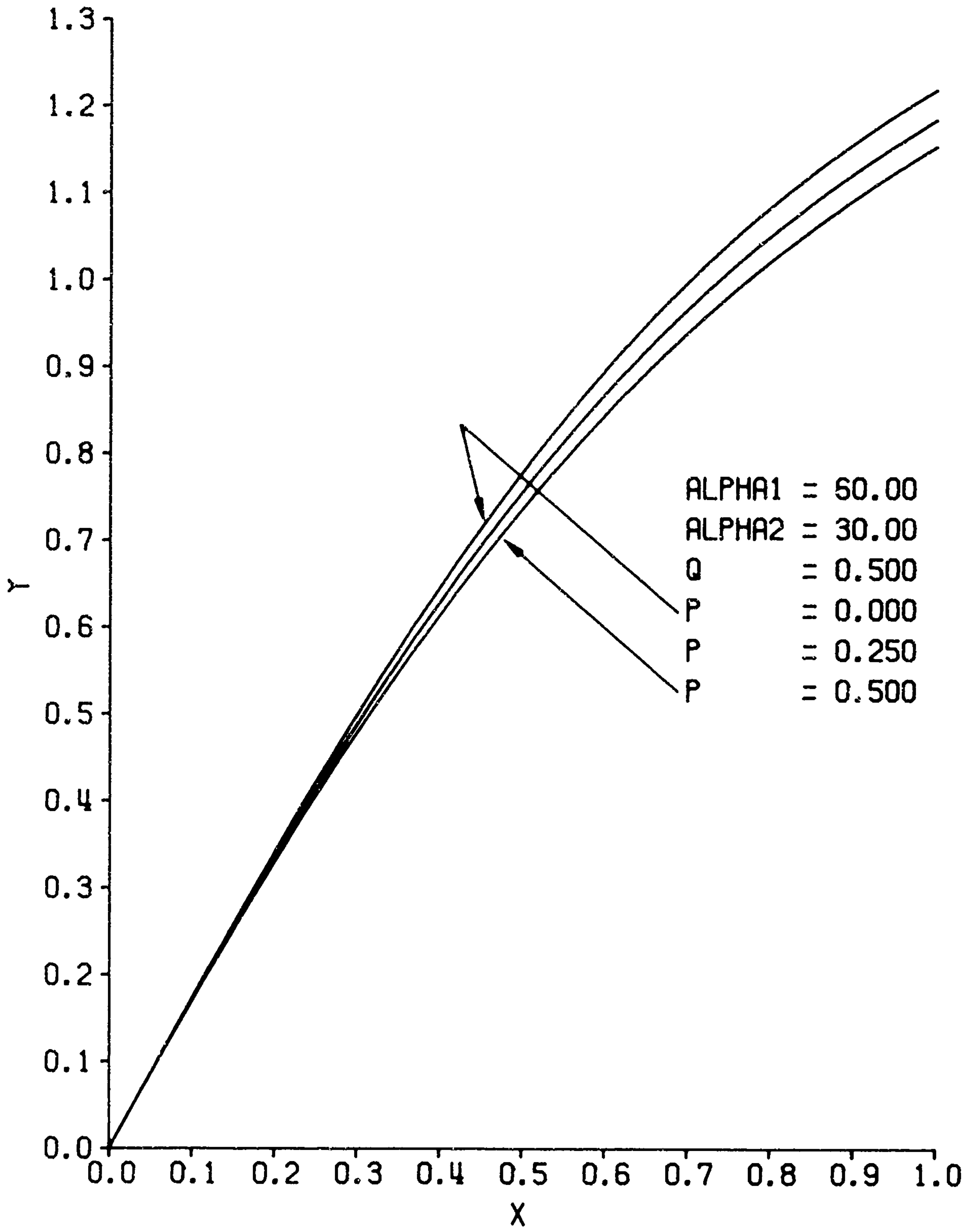


Figure 2 Variation of Polynomial Camber Line with Parameter P

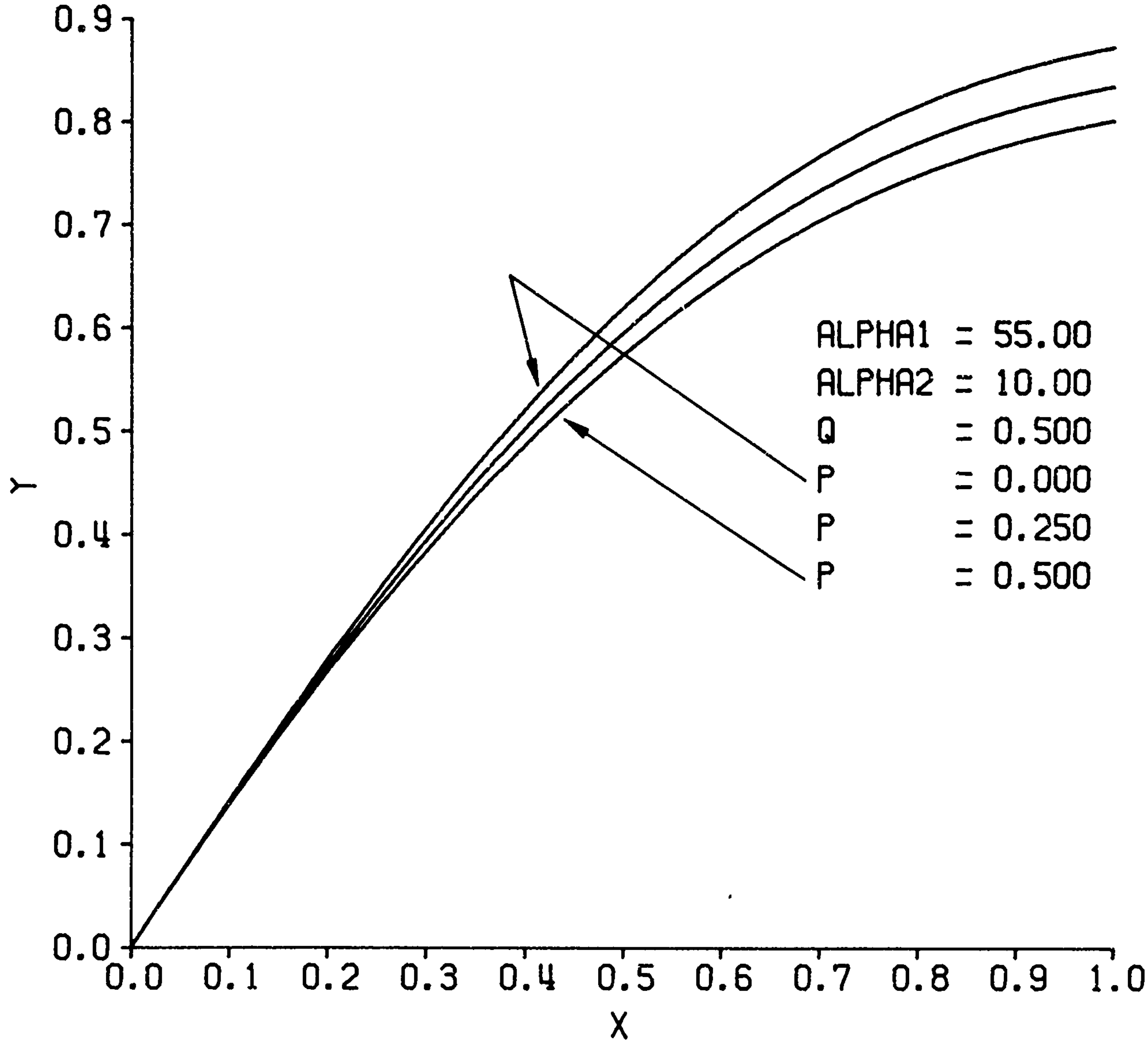


Figure 3 Variation of Polynomial Camber Line with Parameter 'P'

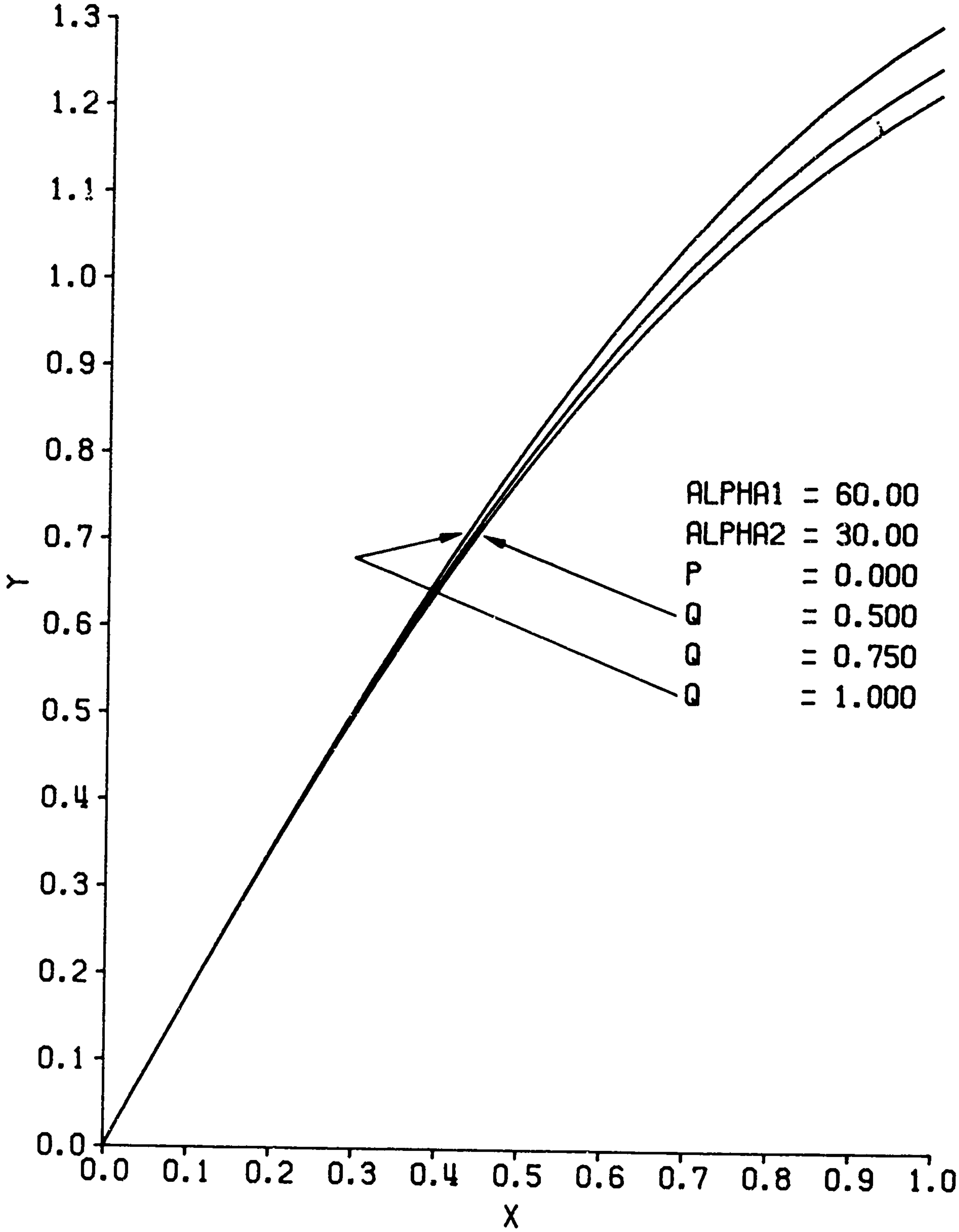


Figure 4 Variation of Polynomial Camber Line with Parameter 'Q'

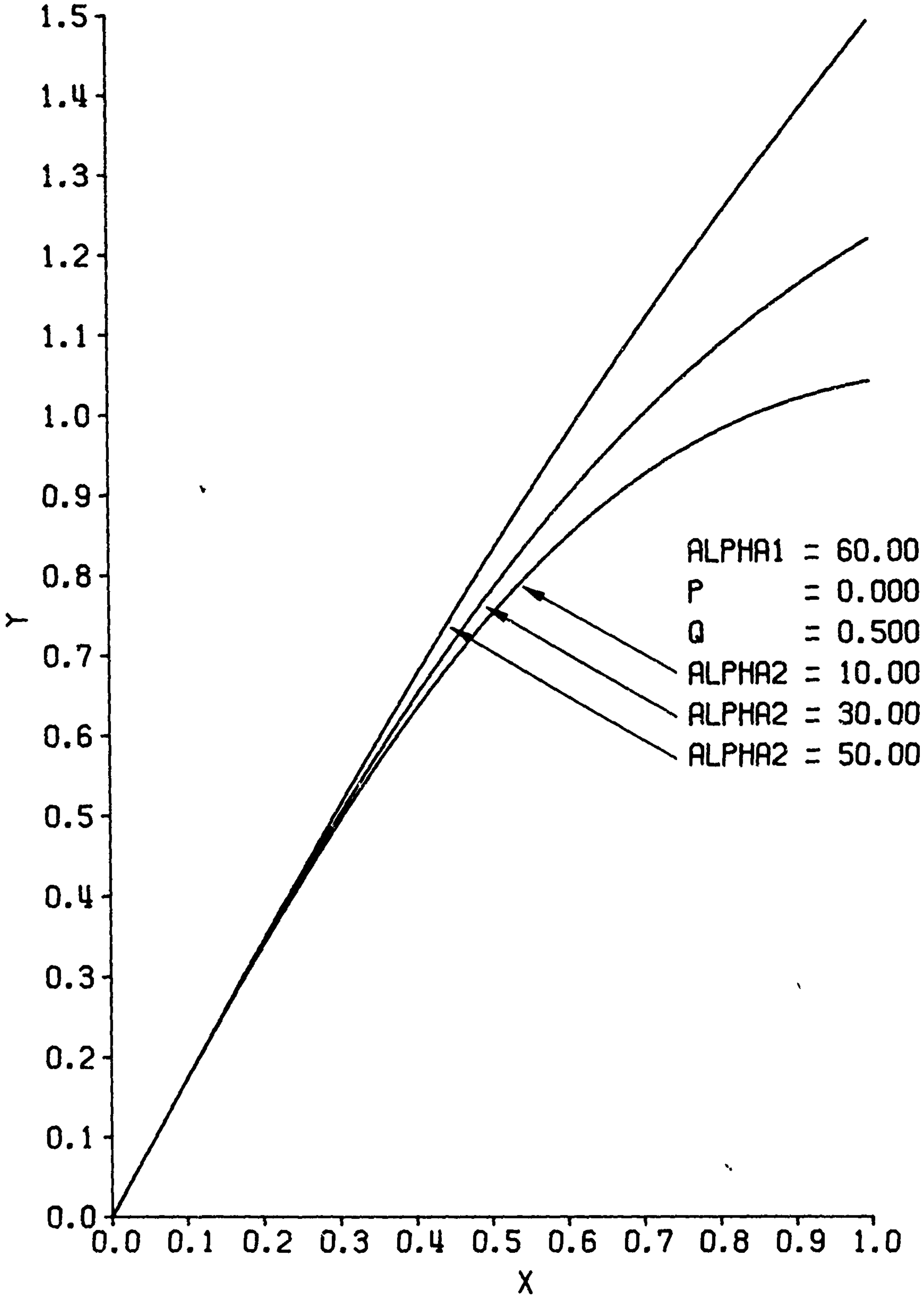


Figure 5 Variation of Polynomial Camber Line with Alpha 2

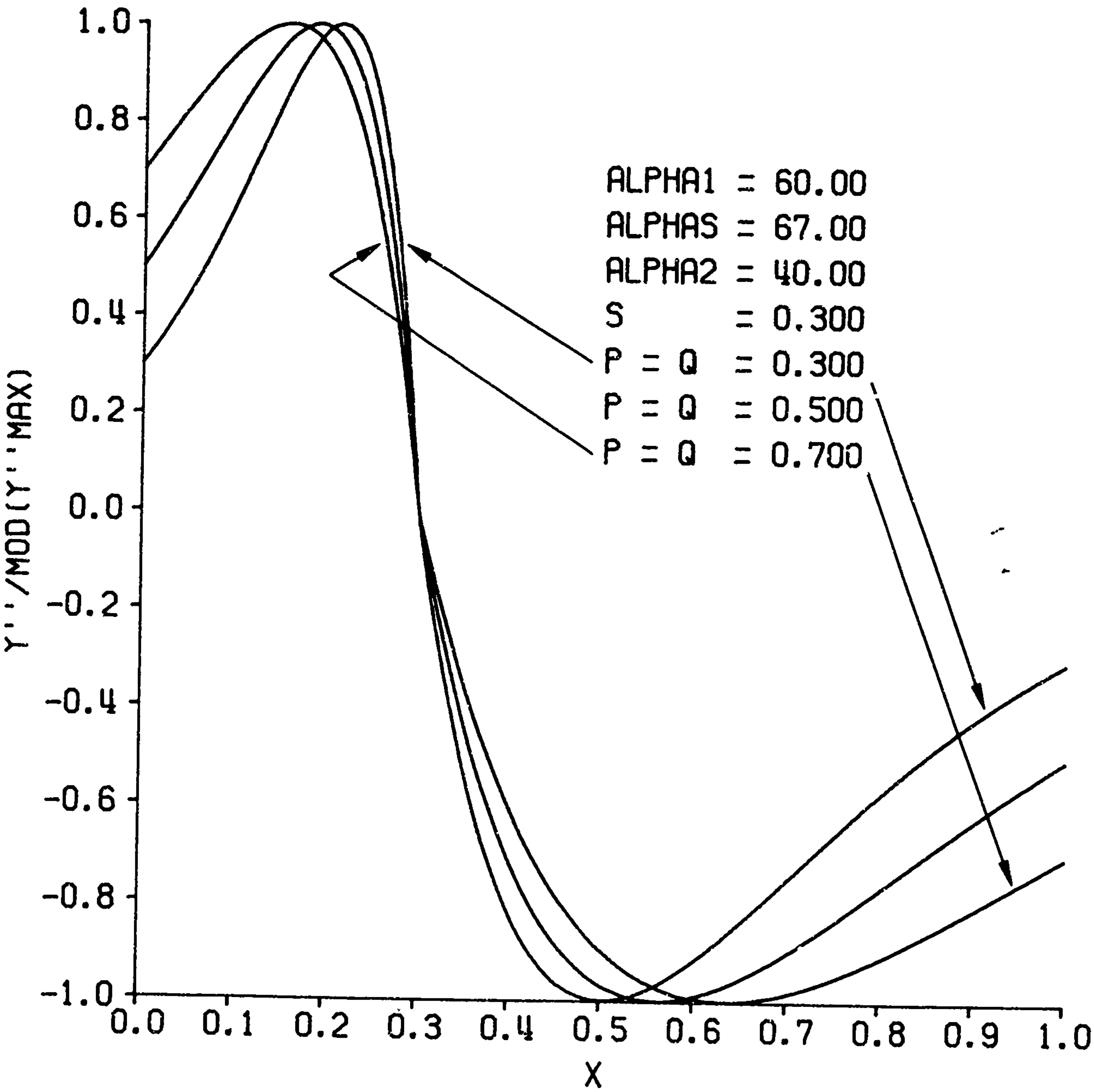


Figure 6 Variation of Normalized Second Derivative of Exponential Camber Line with Parameters 'P' and 'Q'

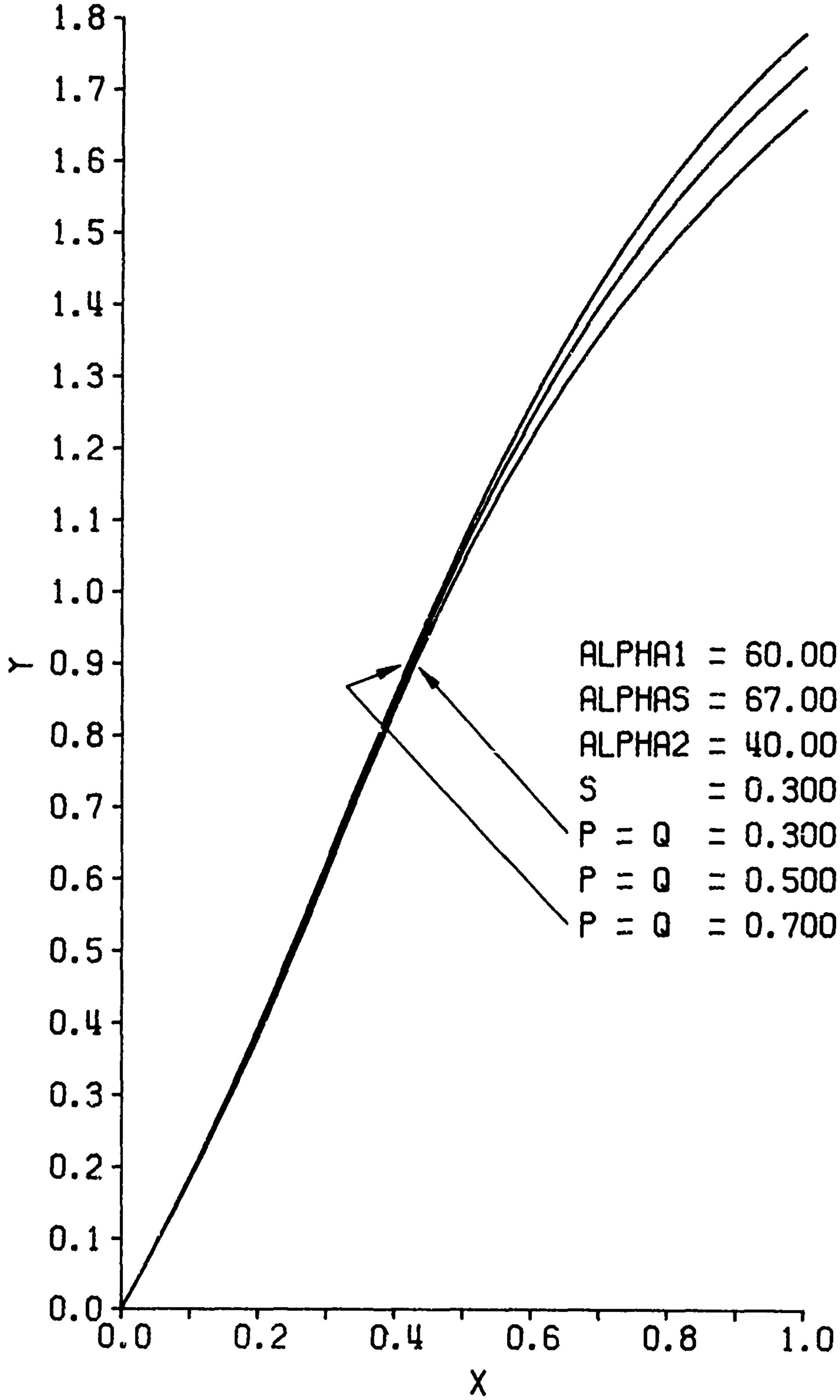


Figure 7 Variation of Exponential Camber Line with Parameters 'P' and 'Q'

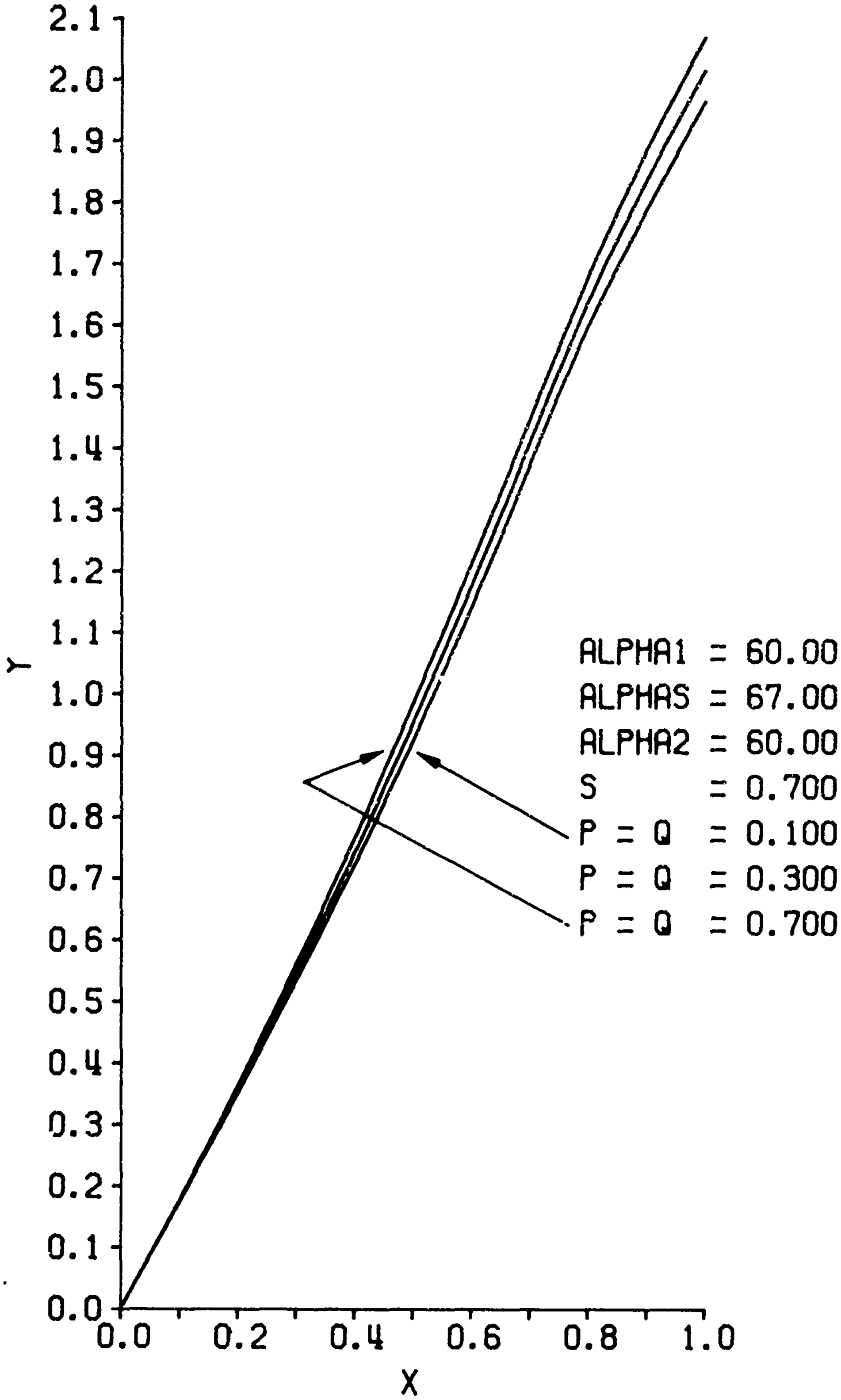
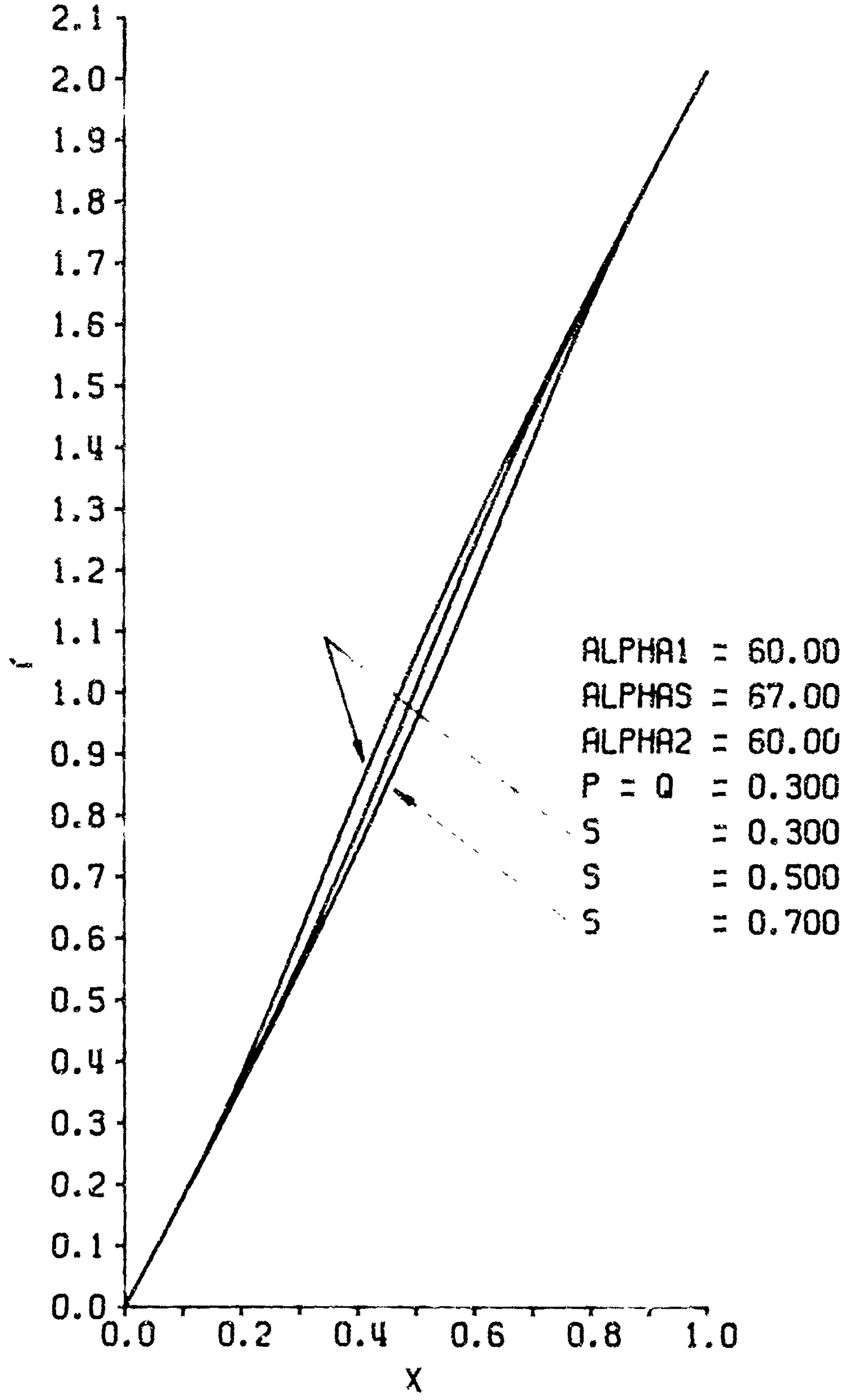


Figure 8 Variation of Exponential Camber Line with Parameters 'P' and 'Q'


2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
0.2
0.4
0.6
0.8
1.0
X
ALPHA1 = 60.00
ALPHAS = 67.00
ALPHA2 = 60.00
P = Q = 0.300
S = 0.300
S = 0.500
S = 0.700

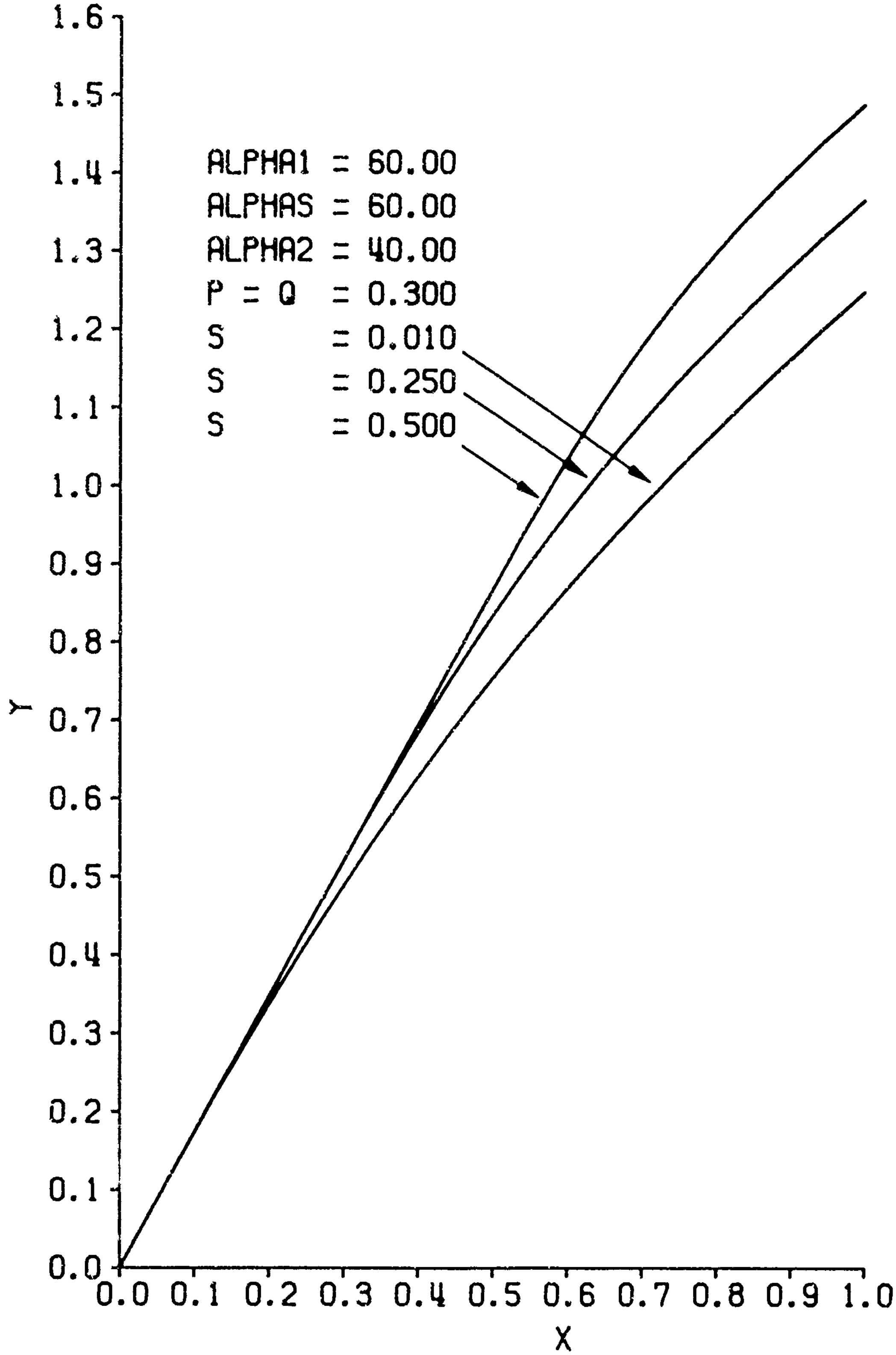


Figure [illegible]. Variation of Exponential Camber Line with Parameter 'S'

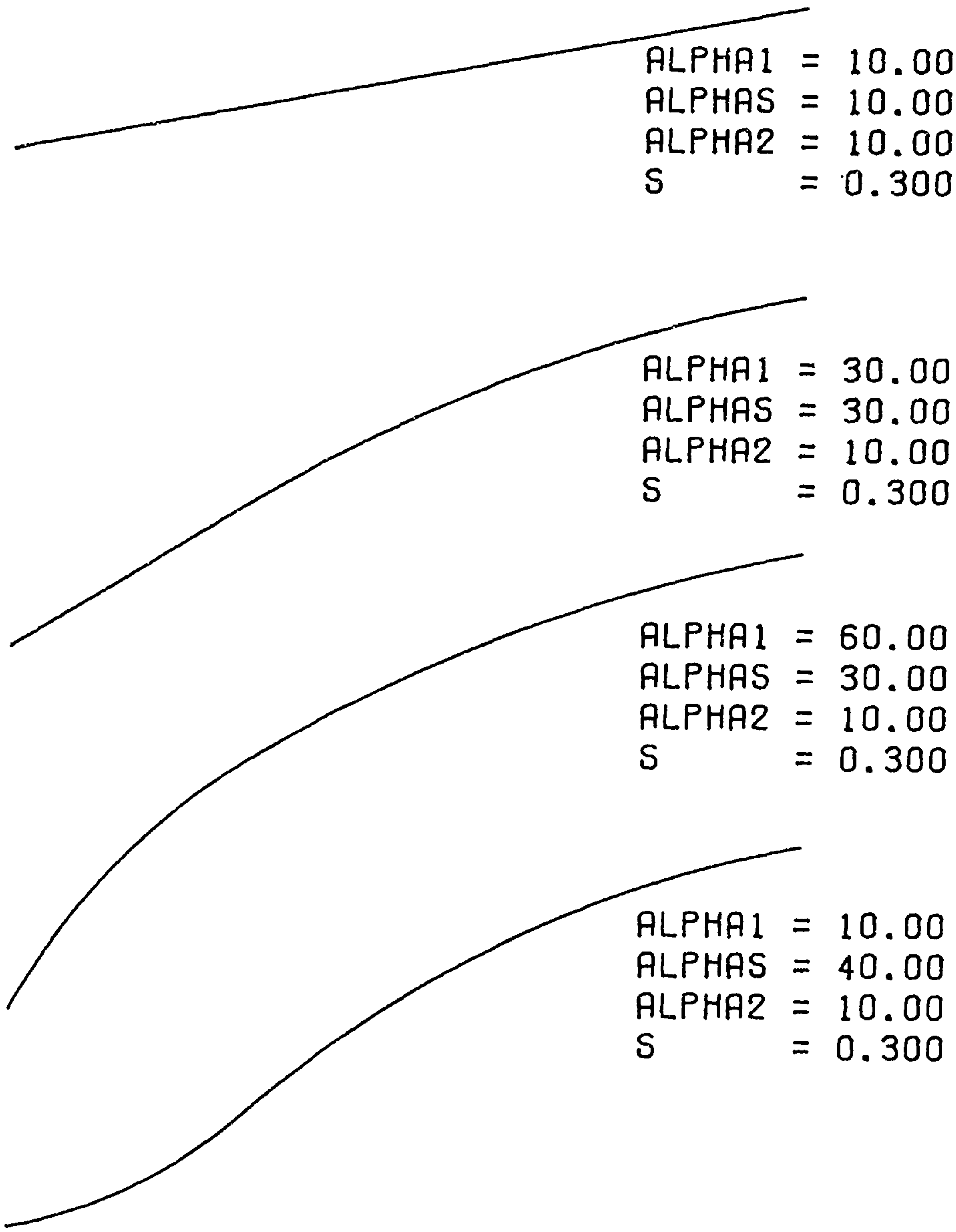


Figure 11 Some Camber Lines Available Under the Multiple-Circular-Arc Camber Line Option

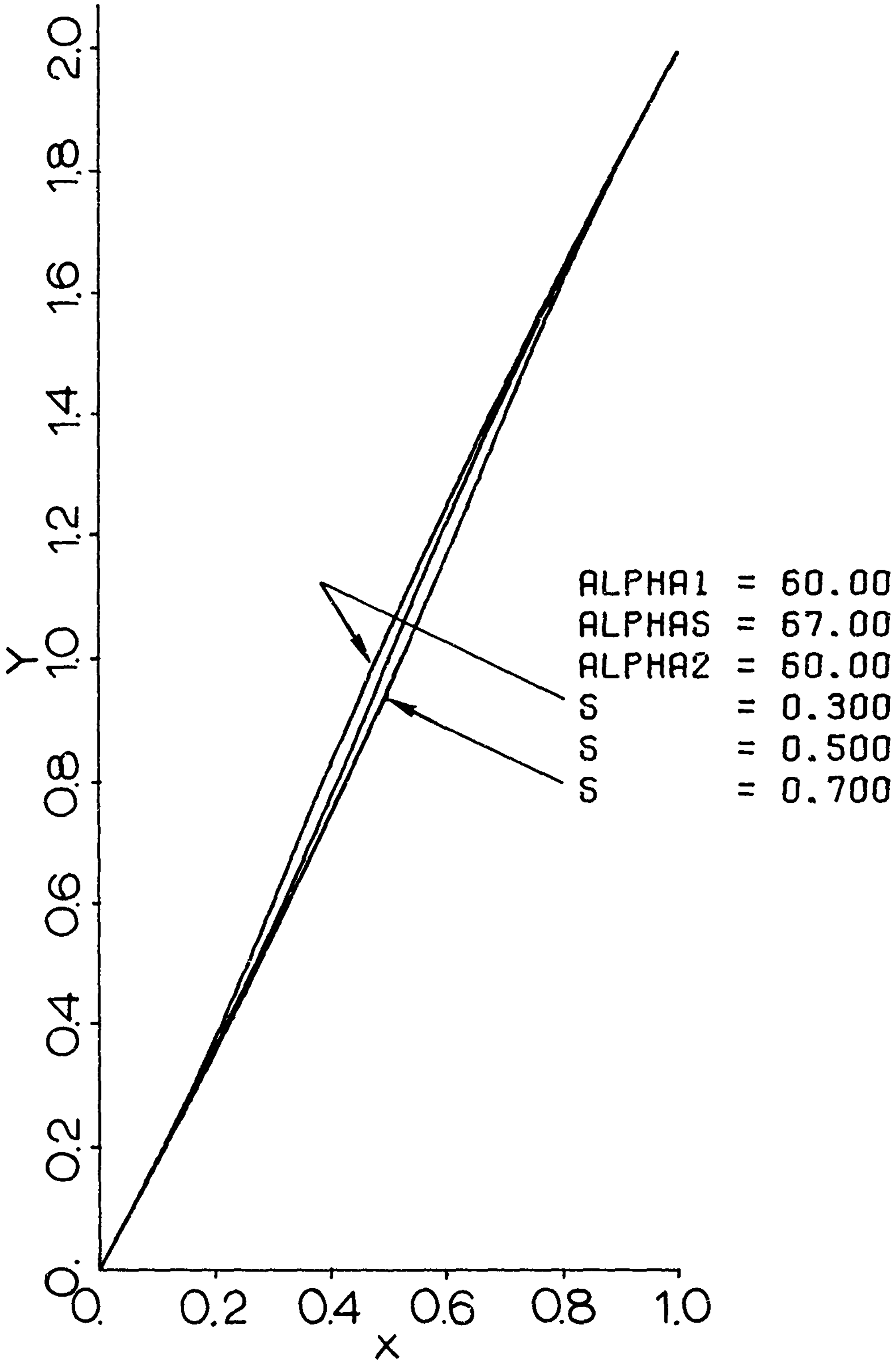


Figure 12 Variation of Multiple-Circular-Arc Camber Line with Parameter 'S'

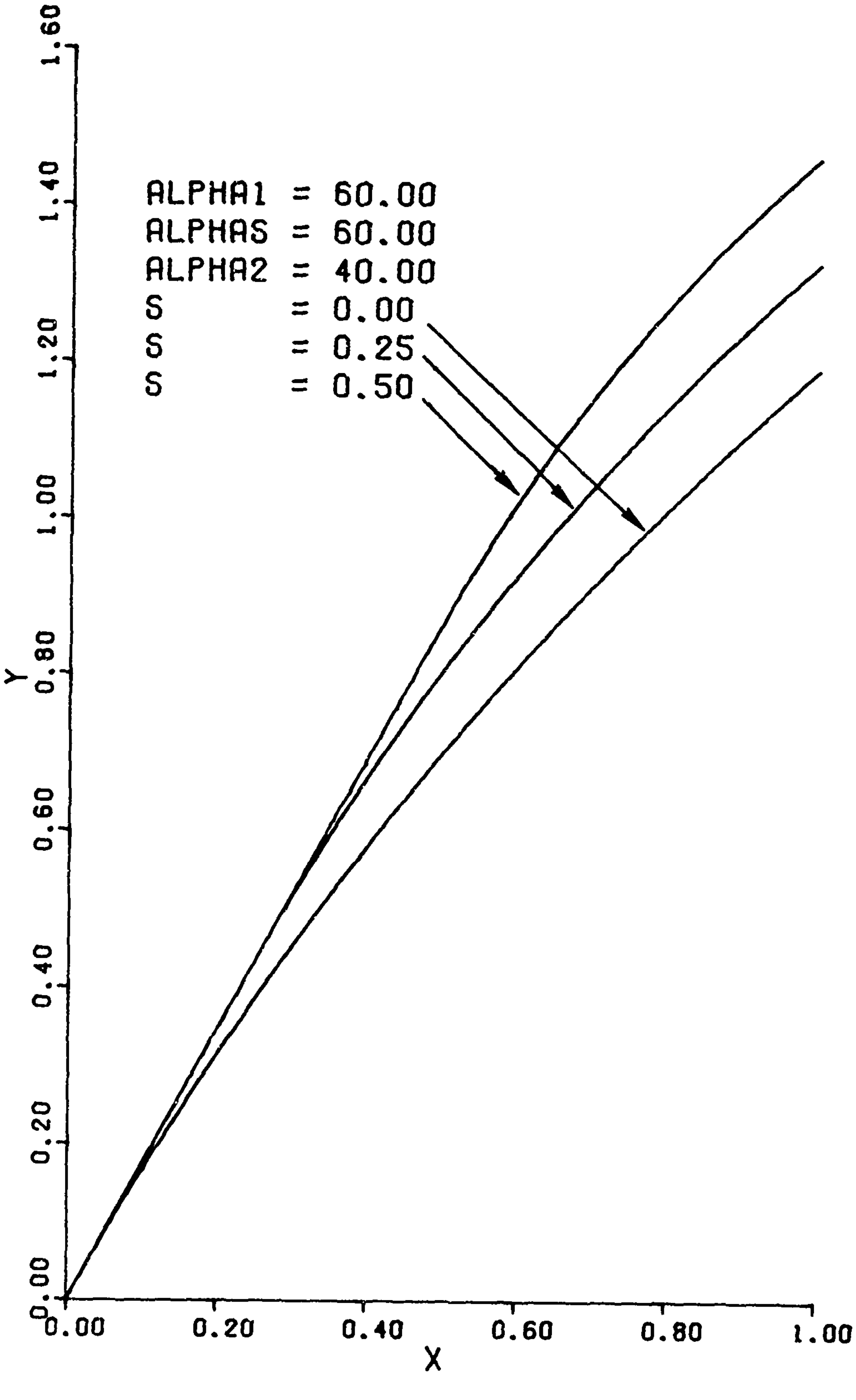


Figure 13 Variation of Multiple-Circular-Arc Camber Line with Parameter 'S'

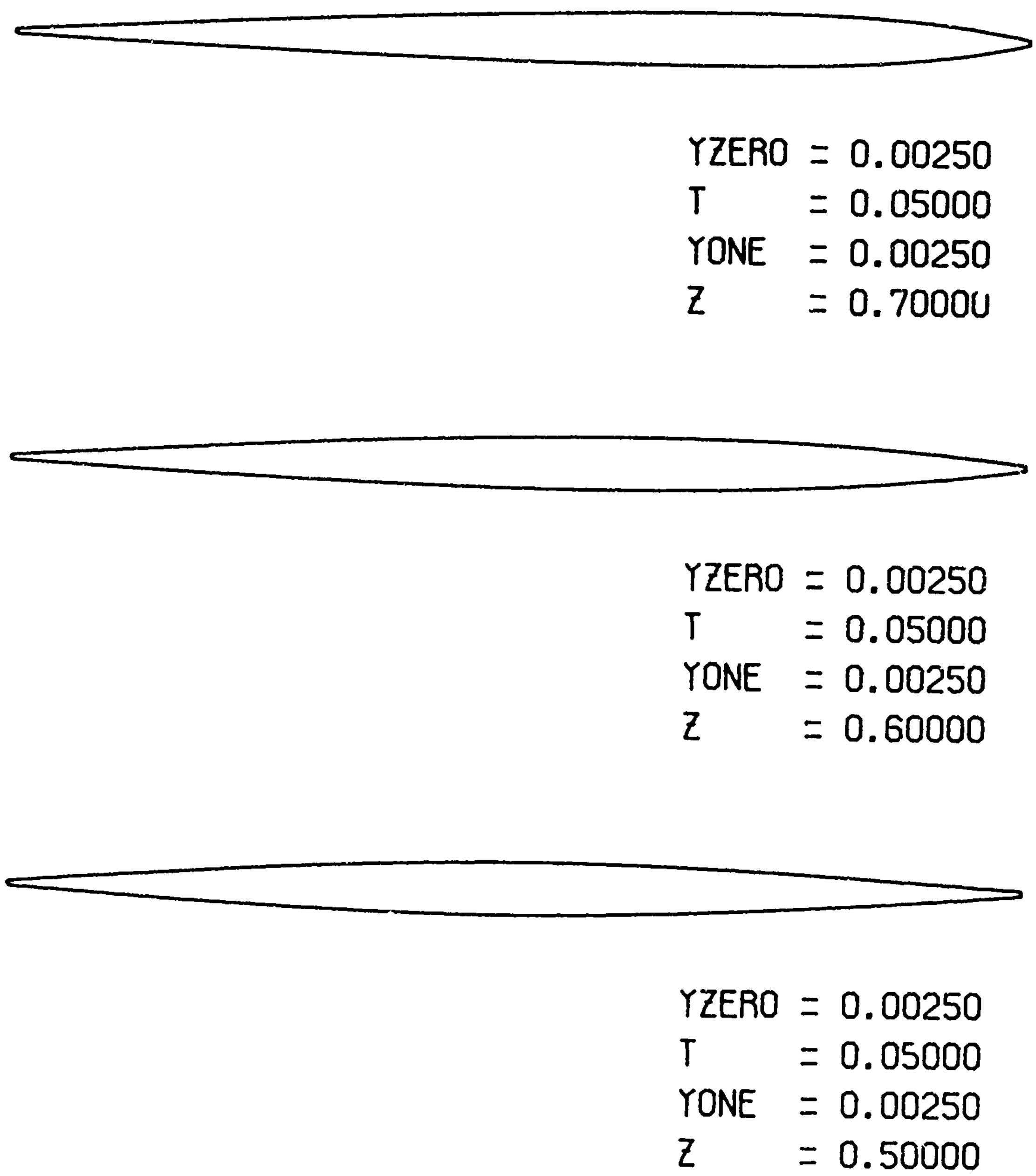


Figure 14 Variation of Thickness Distribution with Point of Maximum Thickness

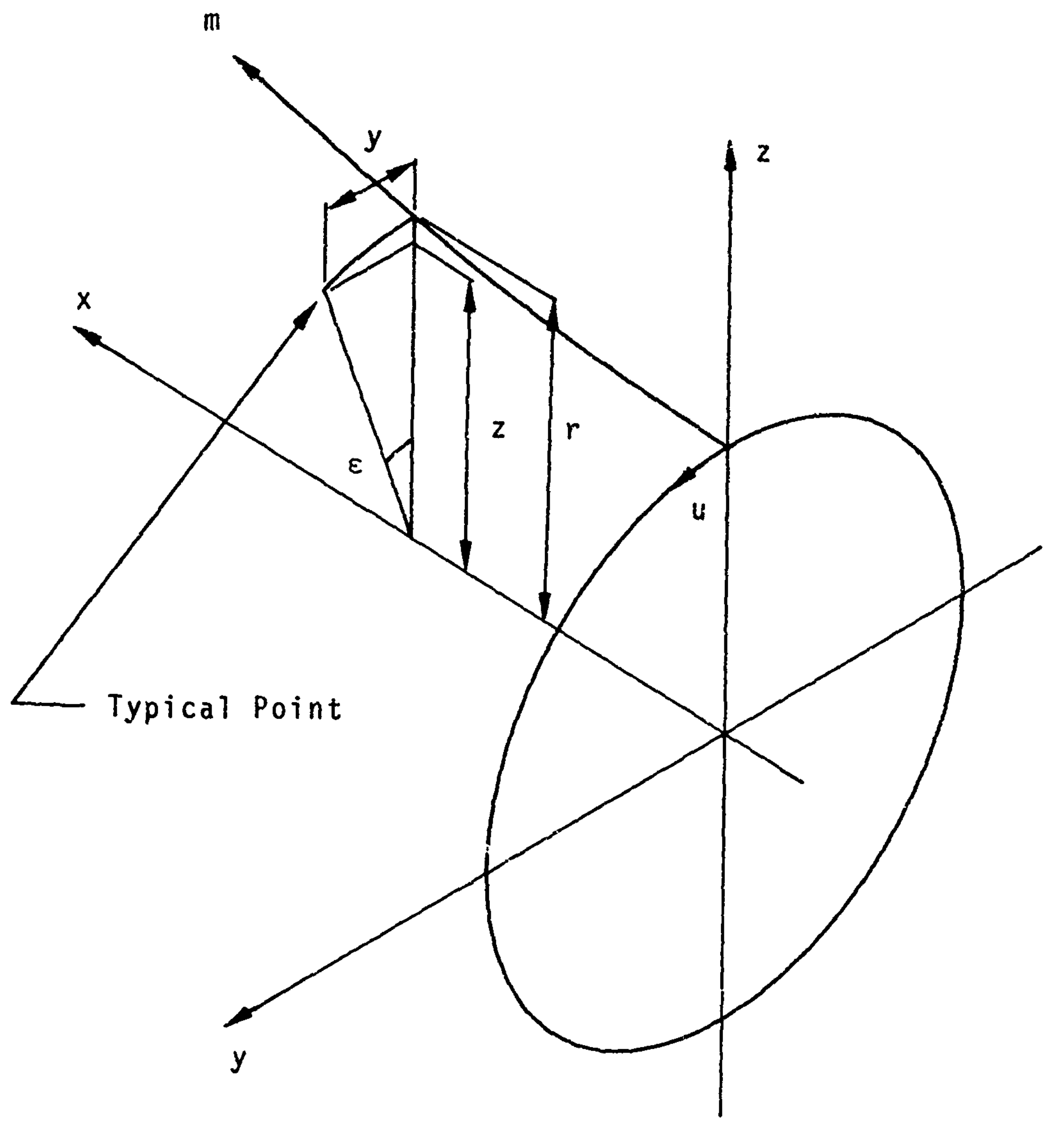
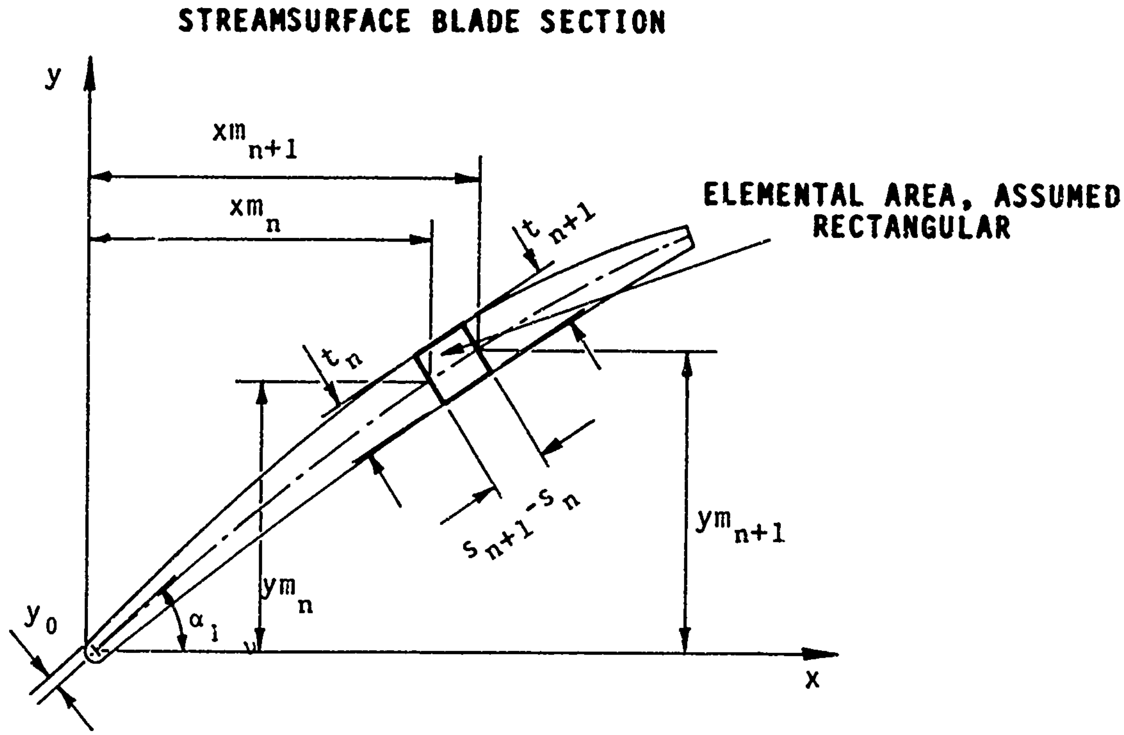


Figure 15 Cartesian and Streamsurface Coordinates of a Point



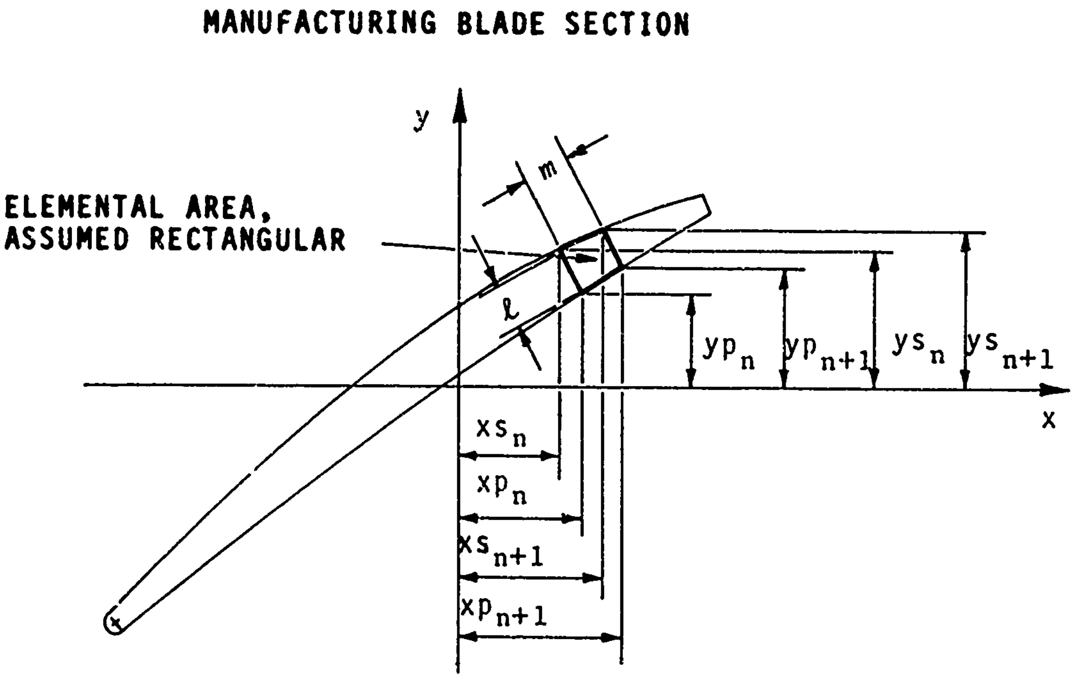
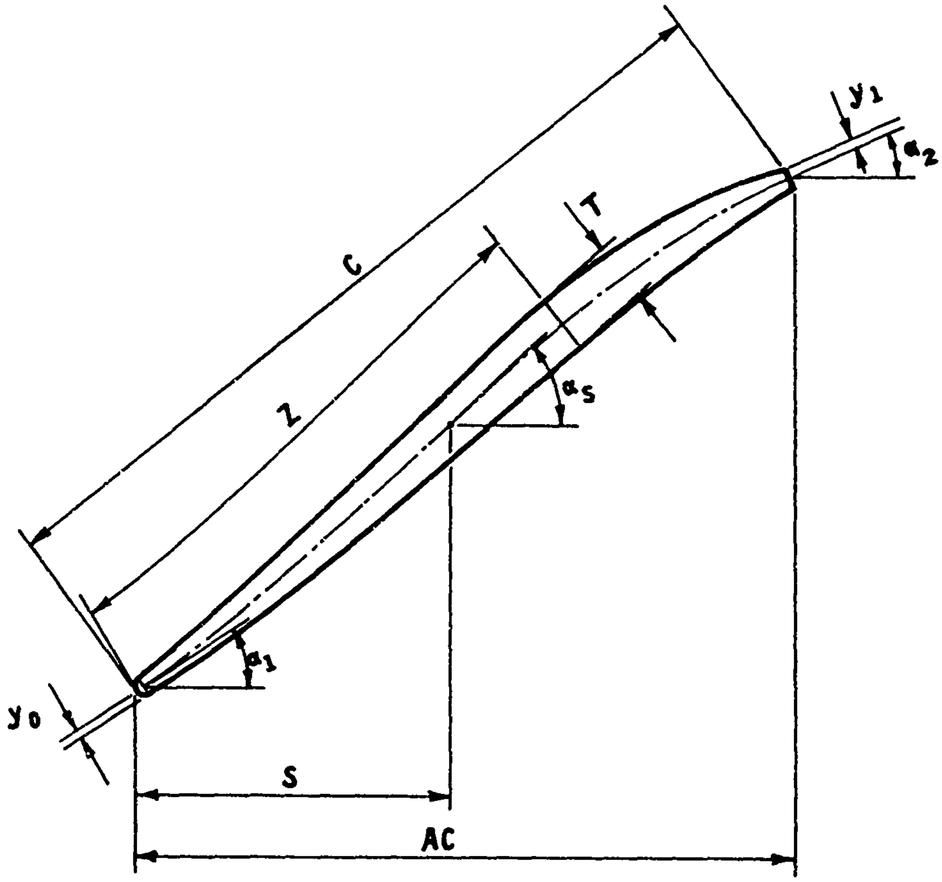


Figure 16 Calculation of Section Properties



SYMBOL	DESCRIPTION	RELATED INPUT DATA ITEM
α_1	Inlet Angle	B1
α_2	Outlet Angle	B2
y_0	Leading Edge Radius	RLE = y_0/C
T	Maximum Thickness	TC = T/C
y_1	Trailing Edge Half-Thickness	TE = y_1/C
Z	Location of Maximum Thickness	Z = z (Camberline Length)
C	Chord	CORD if IFCORD = 1
AC	Axially-Projected Chord	CORD if IFCORD = Ø
s	Inflection Point	S = s/AC
α_s	Inflection Point Angle	BS + B1

Figure 17 Parameters Describing Blade Sections

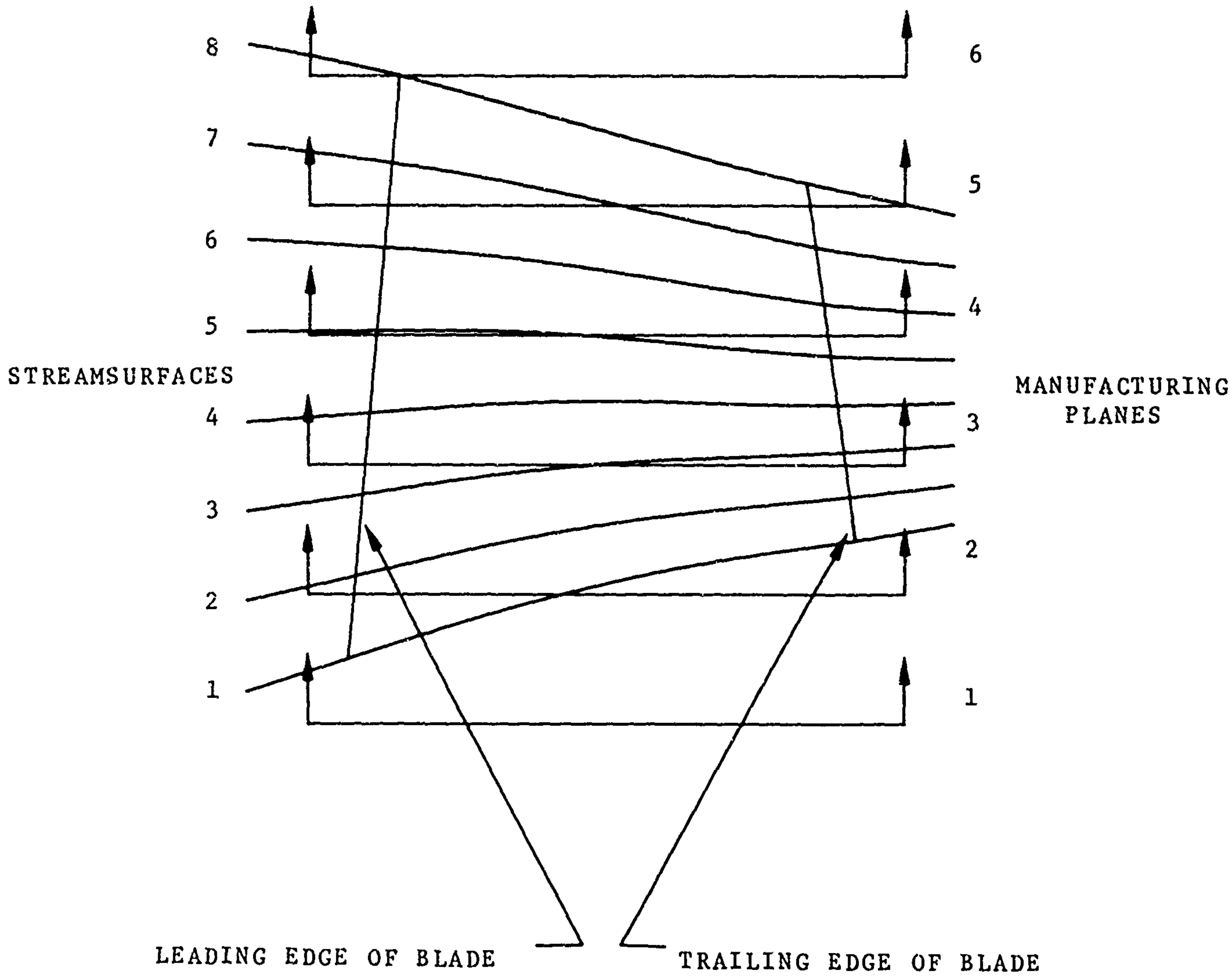
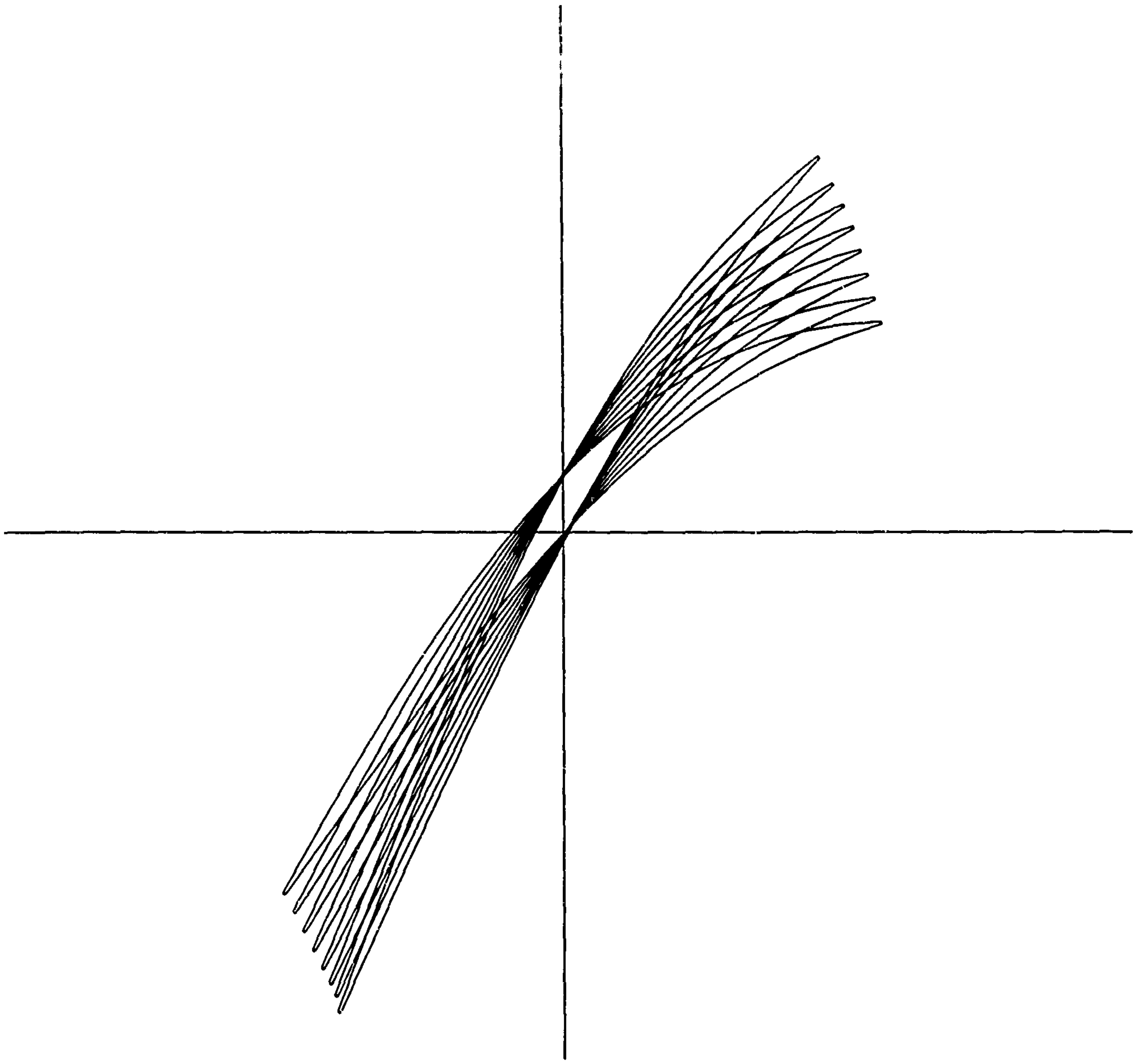
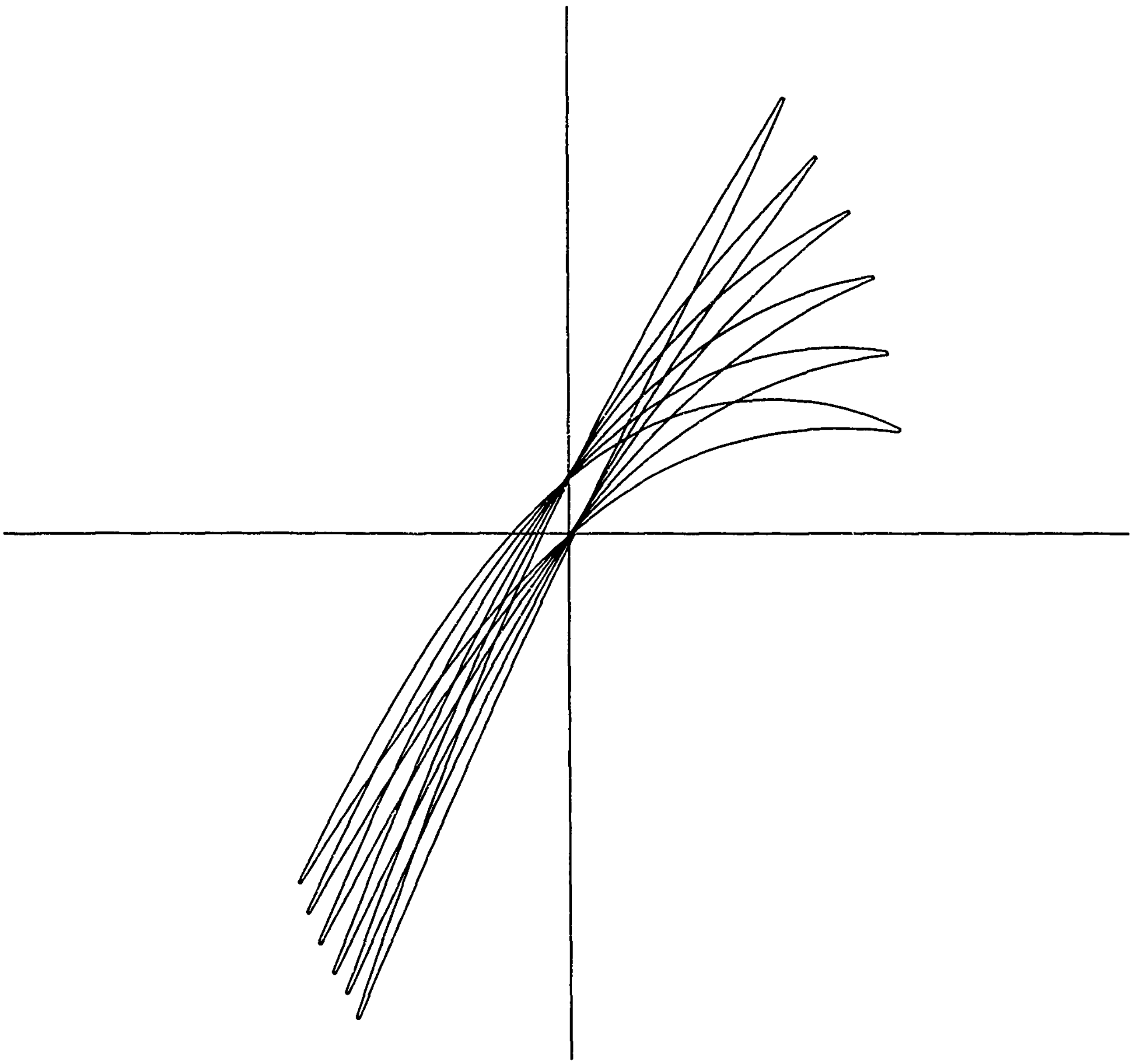


Figure 18 Locations of Streamsurfaces and Manufacturing Planes for Example Blade Designs



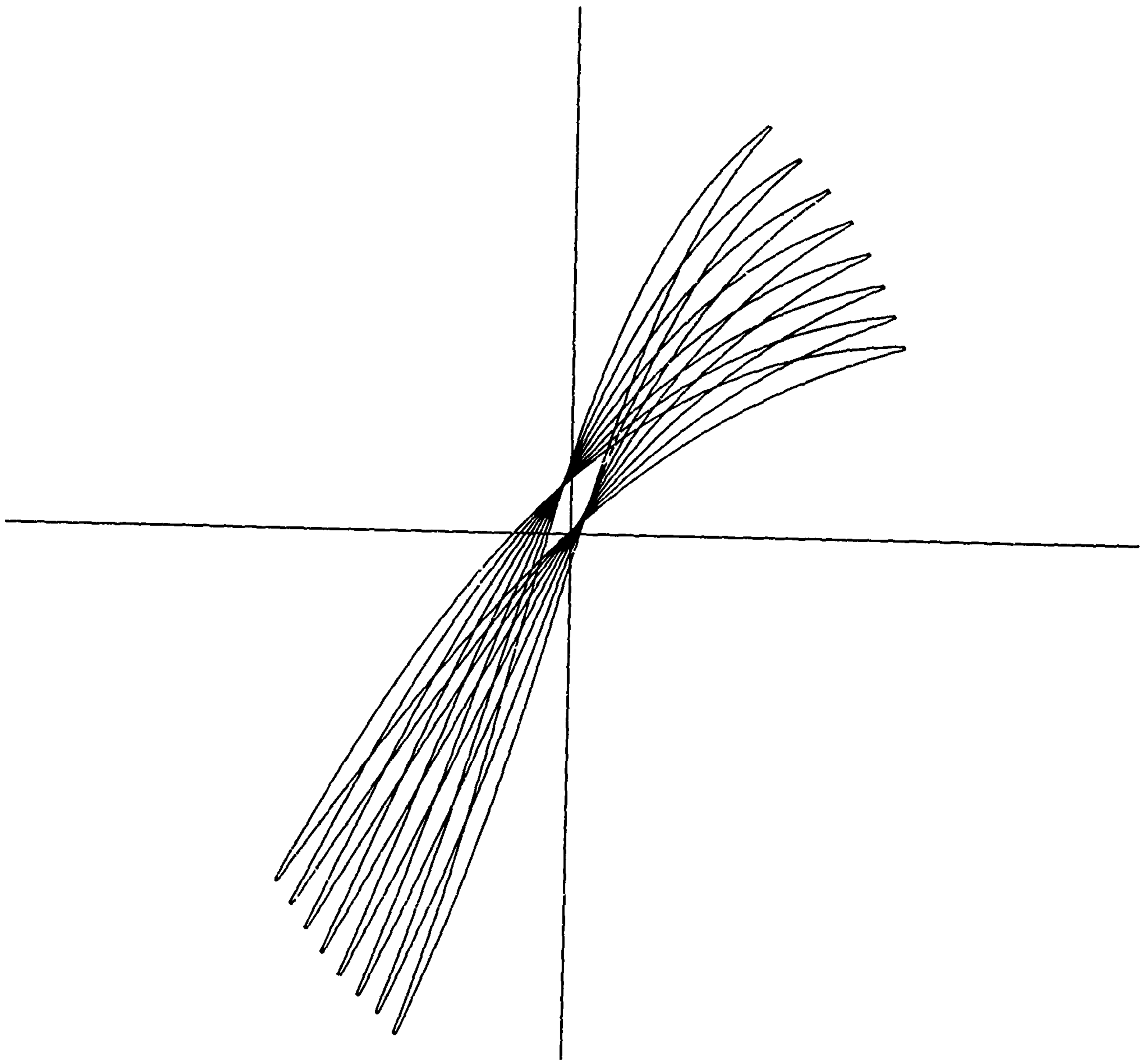
Streamsurface Sections

Figure 19 Example Blade Design - Polynomial Camber Line



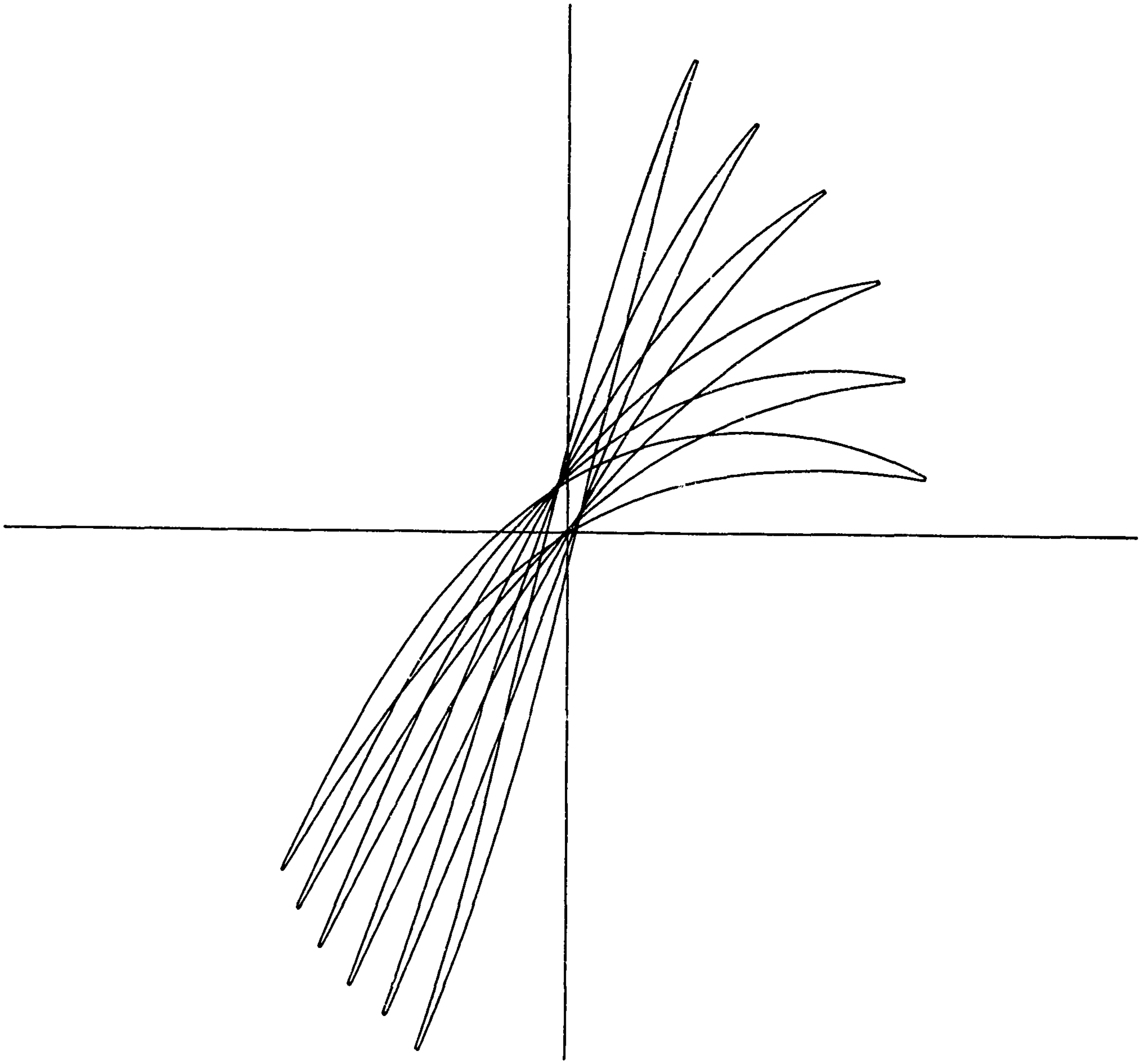
Cartesian Sections

Figure 20 Example Blade Design - Polynomial Camber Line



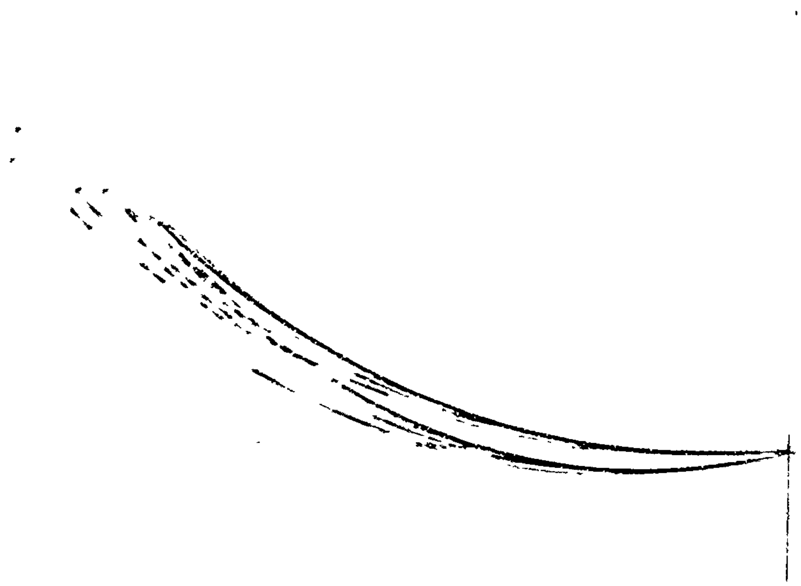
Streamsurface Sections

Figure 21 Example Blade Design - Exponential Camber Line



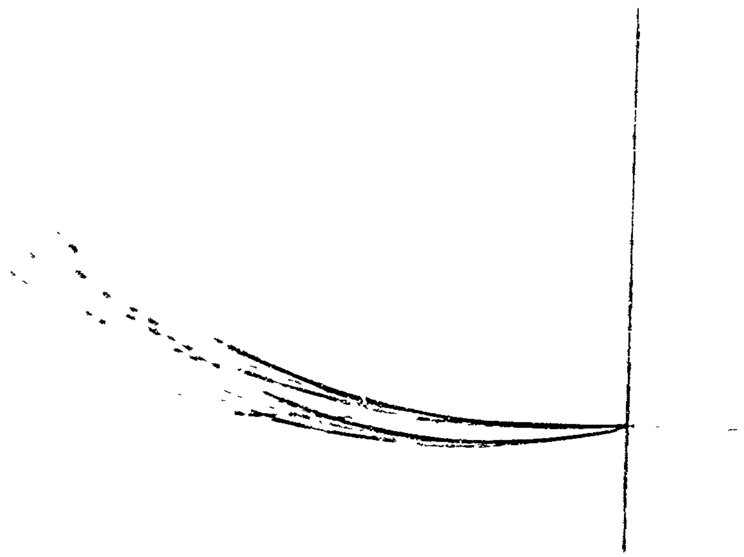
Cartesian Sections

Figure 22 Example Blade Design - Exponential Camber Line



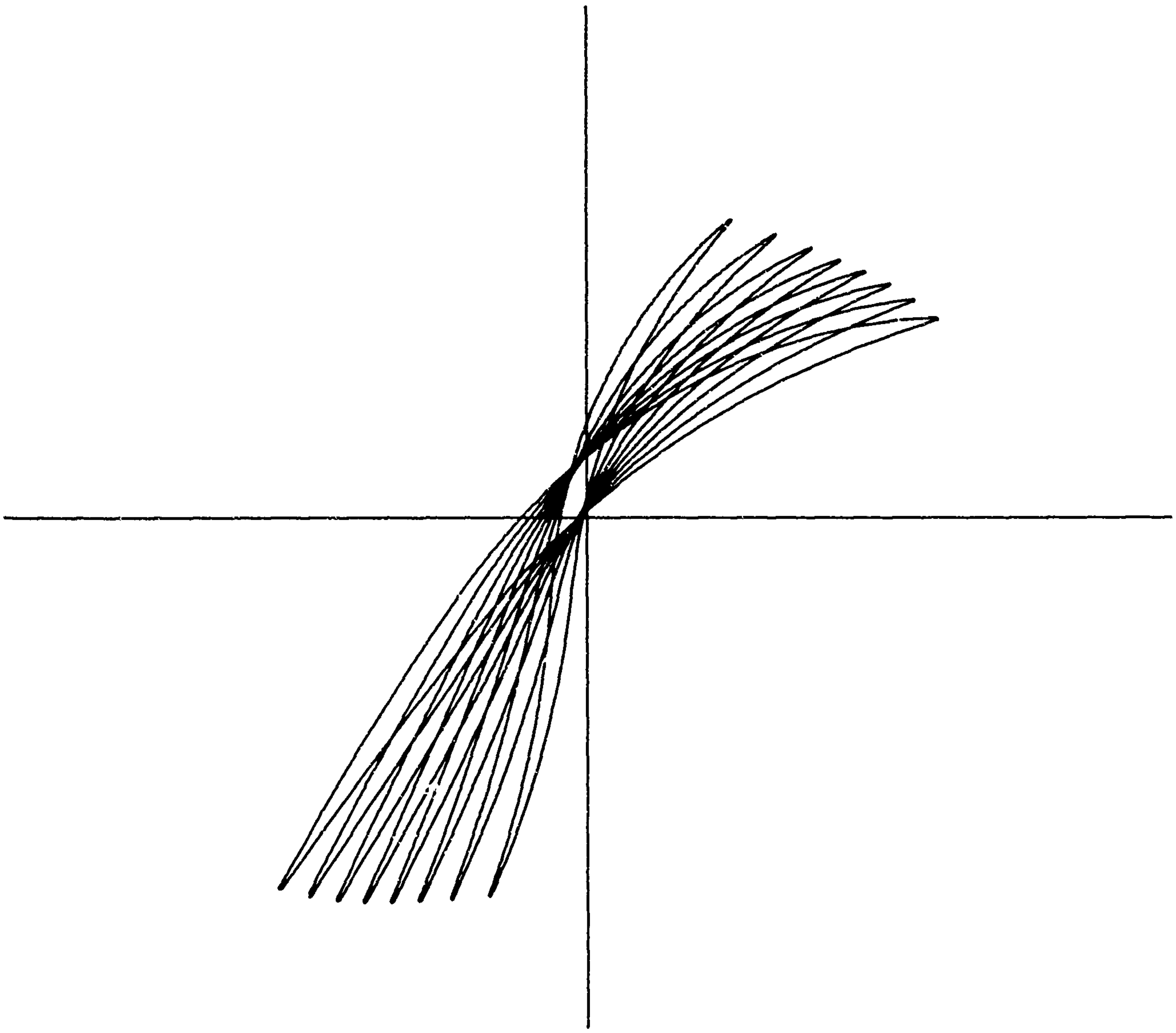
Streamsurface Sections

Figure 23 Example Blade Design - Double-Circular-Arc Blade



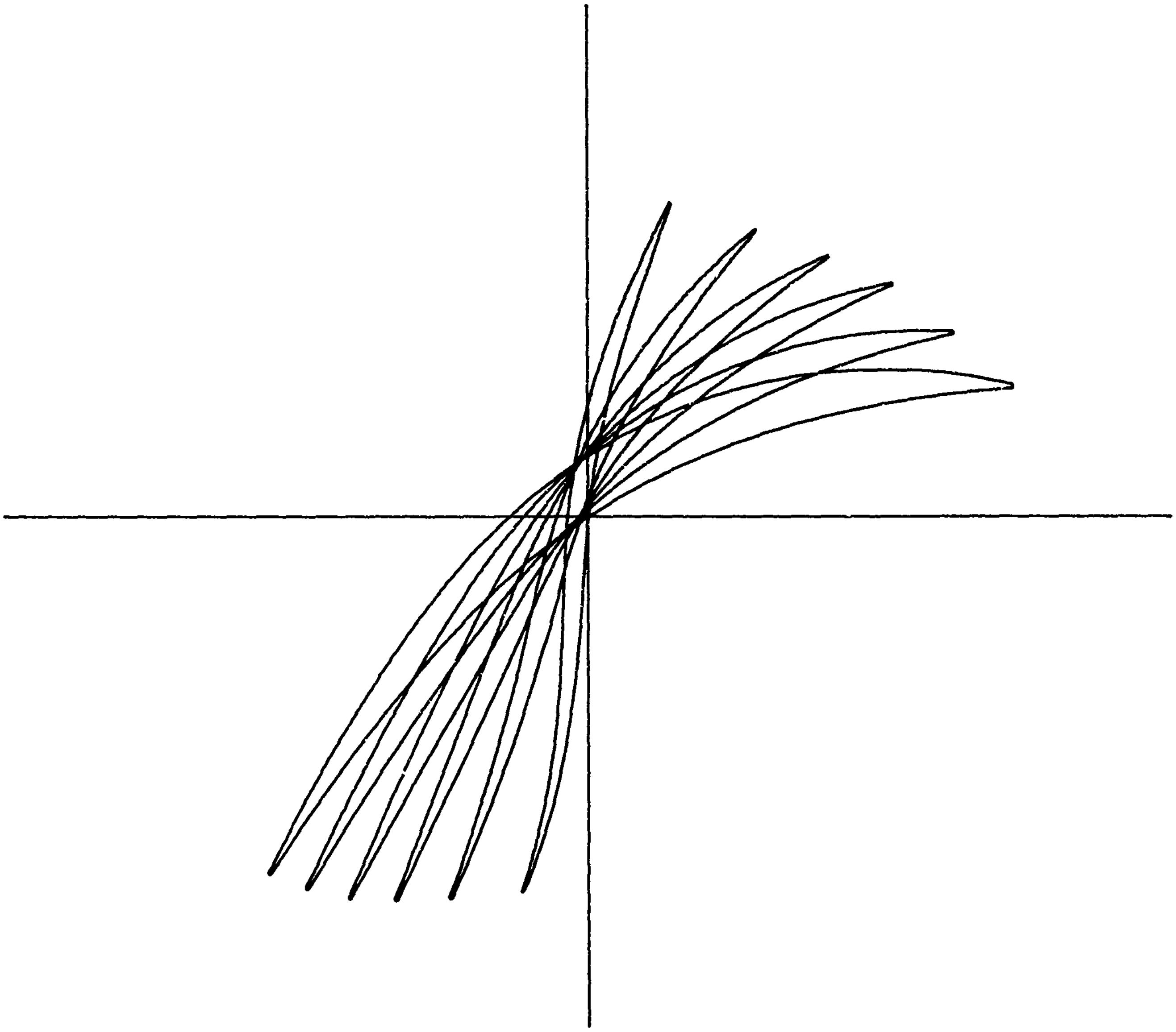
Cartesian Sections

Figure 24 Example Blade Design - Double-Circular-Arc Blade



Streamsurface Sections

Figure 25 Example Blade Design - Multiple-
Circular-Arc Camber Line



Cartesian Sections

Figure 26 Example Blade Design - Multiple-Circular-Arc Camber Line

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